SCIENCE DAY, 28 FEBRUARY

The Science Day is an occasion for all of us—scientists, technologists, students, and *all of us*, young and old—to join together in affirming, and strengthening our commitment and dedication to **Science**, a wonderous and incomparably inspiring exploration of the *TRUTH*, the laws of Nature, governing the Natural World.

It is also the day to recall and evaluate what we did, in and for **Science and Technology**, in the preceding year and to consider what we propose to do in the coming year. To make every day **"a Science Day"** is a real measure of the success of **"The Science Day"**.

Science is a creative and extraordinarily fruitful interaction between Reason, especially Mathematics, and Experiment and Observation. **Science** is an objective, collective and cooperative enterprise of mankind. Since the seventeenth century the growth of science - to begin with in Europe - and the rate of growth, has been fantastic, beyond all expectations.

In our country the tradition of science and technology is deeply rooted in our culture and heritage. And since Independence there has been a new resurgence in teaching and research, and promotion of pioneering developments in agricultural and industrial productivity.

The Modern World, as we all know, is science and technology based, as never before in human history. But there is also rampant violence, brutality, hatred and greed as never before. And today (1991) we are face to face with a supremely dangerous moment in human history of unbelievable violence and cruelty and insanity. There is **Science;** but man has failed miserably to make a **wise use** of it—failed miserably to use **Science and Technology** for promotion of **Truth** and Compassion and **Morality**, that is **AHIMSA**, in our life and actions. No task is more imperative and more vital than to work towards a World based **Both** on **Science** and on **Ahimsa.** To this end our great country, with its living faith, despite so much to the contrary, in tolerence and compassion, in **Ahimsa**, has an especial obligation. Let us join together—scientists and all of us—to humbly renew and reaffirm our dedication to that supremely important and inspiring **Task.**

We should like to express our sincere gratitudes to all whose papers are included in this booklet. It is for limited circulation among the Fellows of the Academy and interested persons.

—Indian National Science Academy

Physics 1930

Presentation Speech by Professor H.Pleijel, Chairman of the Nobel Committee for Physics of the Royal Swedish Academy of Sciences

Your Majesty, Your Royal Highnesses, Ladies and Gentlemen.

The Academy of Sciences, has resolved to award the Nobel Prize in Physics for 1930 to Sir Venkata Raman for his work on the scattering of light and for the discovery of the effect named after him.

The diffusion of light is an optical phenomenon, which has been known for a long time. A ray of light is not perceptible unless it strikes the eye directly. If, however, a bundle of rays of light traverses a medium in which extremely fine dust is present, the ray of light will scatter to the sides and the path of the ray through the medium will be discernible from the side. We can represent the course of events in this way, the small particles of dust begin to oscillate owing to electric influence from the ray of light, and they form centres from which light is dissemminated in all directions The wavelength, or the number of oscillations per second, in the light thus diffused is here the same as in the original ray of light. But this effect has different degrees of strength for light with different wavelengths. It is stronger for the short wavelengths than for the long ones, and consequently it is stronger for the blue part of the spectrum than for the red part. Hence if a ray of light containing all the colours of the spectrum passes through a medium, the yellow and the red rays will pass through the medium without appreciable scattering, whereas the blue rays will be scattered to the sides. This effect has received the name of the "Tyndall effect".

Lord Rayleigh, who has made a study of this effect, has put forward the hypothesis that the blue colours of the sky and the reddish colouring that is observed at sunrise and sunset is caused by the diffusion of light owing to the fine dust or the particles of water in the atmosphere The blue light from the sky would thus be light-scattered to the sides, while the reddish light would be light that passes through the lower layers of the atmosphere and which has become impoverished in blue rays owing to scattering. Later, in 1899, Rayleigh threw out the suggestion that the phenomenon in question might be due to the fact that the molecules of air themselves exercised a scattering effect on the rays of light.

Reproduced From: Nobel Lectures — Physics: 1922-1941 Published for the Nobel Foundation in 1965 by Elsevier Publishing Company, Amsterdam — London — New York

In 1914 Cabannes succeeded in showing experimentally that pure and dustless gases also have the capacity of scattering rays of light.

But a closer examination of scattering in different substances in solid, liquid, or gaseous form showed that the scattered light did not in certain respects exactly follow the laws which, according to calculation, should hold good for the Tyndall effect. The hypothesis which formed the basis of this effect would seem to involve, amongst other things, that the rays scattered to the sides were polarized. This, however, did not prove to be exactly the case.

This divergence from what was to be expected was made the starting-point of a searching study of the nature of scattered light, in which study Raman was one of those who took an active part. Raman sought to find the explanation of the anomalies in asymmetry observed in the molecules During these studies of his in the phenomenon of scattering. Raman made, in 1928, the unexpected and highly surprising discovery that the scattered light showed not only the radiation that derived from the primary light but also a radiation that contained other wavelengths, which were foreign to the primary light.

In order to study more closely the properties of the new rays, the primary light that was emitted from a powerful mercury lamp was filtered in such a way as to yield a primary light of one single wavelength. The light scattered from that ray in a medium was watched in a spectrograph, in which every wavelength or frequency produces a line. Here he found that, in addition to the mercury line chosen, there was obtained a spectrum of new sharp lines, which appeared in the spectrograph on either side of the original line. When another mercury line was employed, the same extra spectrum showed itself round it Thus, when the primary light was moved, the new spectrum followed, in such a way that the frequency distance between the primary line and the new lines always remained the same.

Raman investigated the universal character of the phenomenon by using a large number of substances as a scattering medium, and everywhere found the same effect.

The explanation of this phenomenon, which has received the name of the "Raman effect" after its discoverer, has been found by Raman himself, with the help of the modern conception of the nature of light. According to that conception, light cannot be emitted from or absorbed by material otherwise than in the form of definite amounts of energy or what are known as "light quanta". Thus the energy of light would possess a kind of atomic character. A quantum of light is proportionate to the frequency of rays of light, so that in the case of a frequency twice as great, the quanta of the rays of light will also be twice as great.

In order to illustrate the conditions when an atom emits or absorbs light energy, we can, according to Bohr, picture to ourselves the atom as consisting of a nucleus,

charged with positive electricity round which negative electrons rotate in circular paths at various distances from the centre. The path of every such electron possesses a certain energy, which is different for different distances from the central body.

Only certain paths as stable. When the electron moves in such a path, no energy is emitted. When, on the other hand, an electron falls from a path with higher energy to one with lower energy—that is to say, from an outer path to an inner path—light is emitted with a frequency that is characteristic of these two paths, and the energy of radiation consists of a quantum of light Thus the atom can give rise to as many frequencies as the number of different transitions between the stable paths. There is a line in the spectrum corresponding to each frequency.

An incoming radiation cannot be absorbed by the atom unless its light quantum is identical with one of the light quanta that the atom can emit.

Now the Raman effect seems to conflict with this law. The positions of the Raman-lines in the spectrum do not correspond, in point of fact, with the frequencies of the atom itself, and they move with the activating ray. Raman has explained this apparent contradiction and the coming into existence of the lines by the effect of combination between the quantum of light coming from without and the quanta of light that are released or bound in the atom. If the atom, at the same time as it receives from without a quantum of light, emits a quantum of light of a different magnitude, and if the difference between these two quanta is identical with the quantum of light which is bound or released when an electron passes from one path to another, the quantum of light coming from without is absorbed. In that case the atom will emit an extra frequency, which either will be the sum of or the difference between the activating ray and a frequency in the atom itself. In this case these new lines group themselves round the incoming primary frequency on either side of it, and the distance between the activating frequency and the nearest Raman-lines will be identical with the lowest oscillation frequencies of the atom or with its ultrared spectrum. What has been said as to the atom and its oscillations also holds good of the molecule.

In this way we get the ultrared spectrum moved up to the spectral line of the activating light. The discovery of the Raman-line has proved to be of extraordinary great importance for our knowledge of the structure of molecules.

So far, indeed, there have been all but insuperable difficulties in the way of studying these ultrared oscillation, because that part of the spectrum lies so far away from the region where the photographic plate is sensitive. Raman's discovery has now overcome these difficulties, and the way has been opened for the investigation of the oscillations of the nucleus of the molecules. We choose the primary ray within that range of frequency where the photographic plate is sensitive. The ultrated spectrum, in the form of the Raman-lines, is moved up to that region and, in consequence of that, exact measurements of its lines can be effected.

In the same way the ultraviolet spectrum can be investigated with the help of the Raman effect. Thus we have obtained a simple and exact method for the investigation of the entire sphere of oscillation of the molecules.

Raman himself and his fellow-workers have, during the years that have elapsed since the discovery was made, investigated the frequencies in a large number of substances in a solid, liquid, and gaseous state. Investigations have been made as to whether different conditions of aggregation affect atoms and molecules, and the molecular conditions in electrolytic dissociation and the ultrared absorption spectrum of crystals have been studied.

Thus the Raman effect has already yielded important results concerning the chemical constitution of substances; and it is to foresee that the extremely valuable tool that the Raman effect has placed in our hands will in the immediate future bring with it a deepening of our knowledge of the structure of matter.

Sir Venkata Raman. The Royal Academy of Sciences has awarded you the Nobel Prize in Physics for your eminent researches on the diffusion of gases and for your discovery of the effect that bears your name. The Raman effect has opened new routes to our knowledge of the structure of matter and has already given most important results.

I now ask you to receive the prize from the hands of His Majesty.

The Molecular Scattering of Light

SIR CHANDRASEKHARA V. RAMAN

Nobel Lecture, December 11, 1930

The Colour of the Sea

In the history of science, we often find that the study of some natural phenomenon has been the starting-point in the development of a new branch of knowledge. We have an instance of this in the colour of skylight, which has inspired numerous optical investigations, and the explanation of which, proposed by the late Lord Rayleigh, and subsequently verified by observation, forms the beginning of our knowledge of the subject of this lecture. Even more striking, though not so familiar to all, is the colour exhibited by oceanic waters. A voyage to Europe in the summer of 1921 gave me the first opportunity of observing the wonderful blue opalescence of the Mediterranean Sea. It seemed not unlikely that the phenomenon owed its origin to the scattering of sunlight by the molecules of the water. To test this explanation, it appeared desirable to ascertain the laws governing the diffusion of light in liquids, and experiments with this object were started immediately on my return to Calcutta in September, 1921. It soon became evident, however, that the subject possessed a significance extending far beyond the special purpose for which the work was undertaken, and that it offered unlimited scope for research. It seemed indeed that the study of light-scattering might carry one into the deepest problems of physics and chemistry, and it was this belief which led to the subject becoming the main theme of our activities at Calcutta from that time onwards.

The Theory of Fluctuations

From the work of the first few months, it became clear that the molecular scattering of light was a very general phenomenon which could be studied not only in gases and vapours but also in liquids and in crystalline and amorphous solids, and that it was primarily an effect arising from molecular disarray in the medium and consequent local fluctuations in its optical density. Except in amorphous solids, such molecular disarray could presumably be ascribed to thermal agitation, and the experimental results appeared to support this view. The fact that molecules are optically anisotropic and can orientate freely in liquids was found to give rise to an additional type of scattering. This could be distinguished from the scattering due to fluctuations in density by reason of its being practically unpolarized, whereas the latter was

completely polarized in the transverse direction. The whole subject was critically reviewed and the results till then obtained were set out in an essay published by the Calcutta University Press in February 1922.

The various problems requiring solution indicated in this essay were investigated with the aid of a succession of able collaborators. It is possible to mention briefly only a few of the numerous investigations which were carried out at Calcutta during the six years 1922 to 1927. The scattering of light in fluids was studied by Ramanathan over a wide range of pressures and temperatures with results which appeared to support the "fluctuation" theory of its origin. His work also disclosed the remarkable changes in the state of polarization which accompany the variations of intensity with temperature in vapours and in liquids. Liquid mixtures were investigated by Kameswara Rao, and furnished optical proof of the existence in such systems, of simultaneous fluctuations of density, composition, and molecular orientation. Srivastava studied the scattering of light in crystals in relation to the thermal fluctuations of density and their increase with temperature. Ramdas investigated the scattering of light by liquid surfaces due to thermal agitation, and established a relation between surface-tension and surface-opalescence. He also traced the transition from surface-opalescence to volume-opalescence which occurs at the critical temperature. Sogani investigated X-ray diffraction in liquids, in order to connect it with their optical behaviour, and test the application of fluctuation theory to X-ray scattering.

The Anisotropy of Molecules

As stated above, the state of polarization of the light scattered in fluids is connected with the optical anisotropy of the molecules. Much of the work done at Calcutta during the years 1922 to 1927 was intended to obtain data concerning this property and to establish its relations with various optical phenomena. Krishnan examined a great many liquids, and by his work showed very clearly the dependence of the optical anisotropy of the molecule on its chemical constitution Ramakrishna Rao studied the depolarization of scattered light in a very large number of gases and vapours, and obtained information of high importance for the progress of the subject. Venkateswaran studied the scattering of light in aqueous solutions to find the influence on it of electrolytic dissociation Ramachandra Rao investigated liquids having highly elongated molecules and also highly polar substances over a wide range of temperatures, and discovered the influence of molecular shape and molecular association on the depolarization of scattered light in liquids

The interpretation of the observations with liquids involved the development of a molecular theory of light-scattering in dense media which was undertaken by Ramanathan, myself, and Krishnan. A revised opalescence formula was derived which differed from that of Einstein and yielded results in better agreement with observation. Krishnan and myself also published a series of investigations showing how the optical

anisotropy of the molecules deduced from light-scattering could be utilized to interpret the optical and dielectric behaviour of fluids, and also the electric, magnetic, and mechanical birefringence exhibited by them. The conclusions derived from these studies enabled a connection to be established between the molecular anisotropy observed in fluids and the optical, electric, and magnetic aeolotropy exhibited by solids in the crystalline state.

A New Phenomenon

The investigations referred to above were in the main guided by the classical electromagnetic theory of light, the application of which to the problems of light-scattering is chiefly associated with the names of Rayleigh and of Einstein. Nevertheless, the possibility that the corpuscular nature of light might come into evidence in scattering was not overlooked and was in fact elaborately discussed in the essay of February 1922 which was published at least a year before the well-known discoveries of Compton on X-ray scattering. While our experiments in the main appeared to support the electromagnetic theory of light, evidence came to hand at a very early stage of the investigations of the existence of a phenomenon which seemed to stand outside the classical scheme of thought. The scattering of light in transparent fluids is extremely feeble, much weaker in fact than the Tyndall effect usually observed in turbid media. It was experimentally discovered that associated with the Rayleigh-Einstein type of molecular scattering, was another and stillfee bler type of secondary radiation, the intensity of which was of the order of magnitude of a few hundredths of the classical scattering, and differed from it in not having the same wavelength as the primary or incident radiation. The first observation of this phenomenon was made at Calcutta in April 1923 by Ramanathan who was led to it in attempting to explain why in certain liquids (water, ether, methyl and ethyl alcohols), the depolarization of scattered light varied with the wavelength of the incident radiation. Ramanathan found that after exhaustive chemical purification and repeated slow distillation of the liquid in vacuum, the new radiation persisted undiminished in intensity, showing that it was a characteristic property of the substance studied and not due to any fluorescent impurity. Krishnan observed a similar effect in many other liquids in 1924, and a somewhat more conspicuous phenomenon was observed by me in ice and in optical glasses.

The Optical Analogue of the Compton Effect

The origin of this puzzling phenomenon naturally interested us, and in the summer of 1925, Venkateswaran attempted to investigate it by photographing the spectrum of the scattered light from liquids, using sunlight filtered through colour screens, but was unable to report any decisive results. Ramakrishna Rao in his studies on the depolarization of scattering during 1926 and 1927 looked carefully for a

similar phenomenon in gases and vapours, but without success. This problem was taken up again by Krishnan towards the end of 1927. While his work was in progress, the first indication of the true nature of the phenomenon came to hand from a different quarter. One of the problems interesting us at this time was the behaviour in light-scattering of highly viscous organic liquids which were capable of passing over into the glassy state. Venkateswaran undertook to study this question, and reported the highly interesting result that the colour of sunlight scattered in a highly purified sample of glycerine was a brilliant green instead of the usual blue. The phenomenon appeared to be similar to that discovered by Ramanathan in water and the alcohols, but of much greater intensity, and, therefore, more easily studied. No time was lost in following up the matter. Tests were made with a series of filters transmitting narrow regions of the solar spectrum and placed in the path of the incident beam, which showed that in every case the colour of the scattered light was different from that of the incident light, and was displaced from it towards the red. The radiations were also strongly polarized. These facts indicated a clear analogy between the empirical characters of the phenomenon and the Compton effect. The work of Compton had made familiar the idea that the wavelength of radiation could be degraded in the process of scattering, and the observations with glycerine suggested to me that the phenomenon which had puzzled us ever since 1923 was in fact the optical analogue of the Compton effect. This idea naturally stimulated further investigation with other substances.

The chief difficulty which had hitherto oppressed us in the study of the new phenomenon was its extreme feebleness in general This was overcome by using a 7-inch refracting telescope in combination with a short-focus lens to condense sunlight into a pencil of very great intensity With these arrangements and using complementary light-filters in the path of the incident and scattered beams, as was done by Ramanathan in 1923, to isolate the modified radiations, it was found that they could be readily observed in a great many liquids, and that in many cases they were strongly polarized. Krishnan, who very materially assisted me in these investigations, found at the same time that the phenomenon could be observed in several organic vapours, and even succeeded in visually determining the state of polarization of the modified radiations from them. Compressed gases such as CO_2 and N_2O, crystalline ice, and optical glasses also were found to exhibit the modified radiations. These observations left little doubt that the phenomenon was really a species of light-scattering analogous to the Compton effect.

The Spectroscopic Characters of the New Effect

Thanks to the vastly more powerful illumination made available by the 7-inch refractor, the spectroscopic examination of the effect, which had been abandoned in 1925 as indecisive, now came within the reach of direct visual study. With a Zeiss

cobalt-glass filter placed in the path of the incident beam and one or other of a series of organic liquids as the scattering substance, a band in the blue-green region was observed by me in the spectrum of the scattered light, separated by a dark interval from the indigo-violet region transmitted by the filter. *Both* of these regions in the spectrum became sharper when the region of transmission was narrowed by the insertion of an additional filter in the incident beam. This suggested the employment, istead of sunlight, of the highly monochromatic radiations given by a mercury arc in combination with a condenser of large aperture and a cobalt-glass filter. With these arrangements the spectrum of the scattered light from a variety of liquids and solids was visually examined, and the startling observation was made that the spectrum generally included a number of sharp lines or bands on a diffuse background which were not present in the light of the mercury arc.

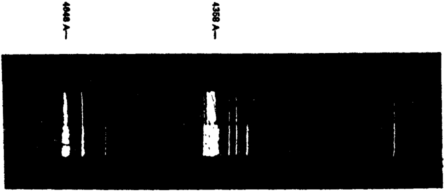


Fig. 1. Spectrum of carbon tetrachloride.

The quartz mercury lamp was so powerful and convenient a source of monochromatic illumination that, at least in the case of liquids and solids, photographing the spectrum of scattered light was found to present no extra-ordinary difficulties. The earliest pictures of the phenomenon were in fact taken with a portable quartz spectrograph of the smallest size made by the firm of Hilger. With a somewhat larger instrument of the same type, Krishnan obtained very satisfactory spectrograms with liquids and with crystals on which measurements of the desired precision could be made, and on which the presence of lines displaced towards the violet was first definitely established. The experimental difficulties were naturally greater in the case of gases or vapours, though they could be lessened by working with the substance under pressure. With an improvised instrument of large aperture (F/1.8), Ramdas obtained the first spectrograms with a gaseous substance (ether vapour) at atmospheric pressure.

In interpreting the observed phenomena, the analogy with the Compton effect was adopted as the guiding principle. The work of Compton had gained general

acceptance for the idea that the scattering of radiation is a unitary process in which the conservation principles hold good. Accepting this idea it follows at once that, if the scattering particle gains any energy during the encounter with the quantum, the latter is deprived of energy to the same extent, and accordingly appears after scattering as a radiation of diminished frequency. From thermodynamic principles, it follows that the reverse process should also be possible. Adopting these ideas, the actual observations could be interpreted, and the agreement of the observed displacements with the infrared frequencies of the molecules made it clear that the new method opened up an illimitable field of experimental research in the study of the structure of matter.

Interpretation of the Effect

It appears desirable to emphasize that though the conservation principle of Compton is useful in interpreting the effects disclosed by experiment, it is by itself insufficient to explain the observed phenomena. As is well known from studies on molecular spectra, a gaseous molecule has four diffierent species of energy of increasing orders of magnitude, namely those corresponding to translatory motion, rotation, vibration, and electronic excitation. Each of these, except the first, is quantized and may be represented by an integer in an extended sequence of quantum numbers. The aggregate energy of a molecule may, therefore, assume any one out of a very large number of possible values. If we assume that an exchange of energy occurs in the collision between the molecule and the quantum, and limit ourself to the cases in which the final energy of the molecule is less than that of the incident quantum, we arrive at the result that the spectrum of the scattered light should contain an immense number of new lines and should in fact rival in its complexity the band spetrum of the molecule observed in the emission or absorption of light. Nothing more diffierent from what is actually observed can be imagined than the foregoing picture. The most conspicuous feature revealed by experiment is the beautiful simplicity of the spectra of even complicated polyatomic molecules obtained in light-scattering, a simplicity that is in striking contrast to the extreme complexity of their emission or absorption spectra. It is this simplicity that gives to the study of light-scattering its special significance and value. It is clear that the effect actually observed was not and could not have been foreseen from an application of the conservation principles.

The general principle of correspondence between the quantum and classical theories enunciated by Niels Bohr enables us, on the other hand, to obtain a real insight into the actual phenomena. The classical theory of light-scattering tells us that if a molecule scatters light while it is moving, rotating or vibrating, the scattered radiations may include certain frequencies, different from those of the incident waves. This classical picture, in many respects, is surprisingly like what we actually observe in the experiments. It explains why the frequency shifts observed fall into three classes, translational, rotational and vibrational, of different orders of magnitude It explains the

observed selection rules, as for instance, why the frequencies of vibration deduced from scattered light include only the fundamentals and not the overtones and combinations which are so conspicuous in emission and absorption spectra. The classical theory can even go further and give us a rough indication of the intensity and polarization of the radiations of altered frequency. Nevertheless, the classical picture has to be modified in essential respects to give even a qualitative description of the phenomena, and we have, therefore, to invoke the aid of quantum principles. The work of Karmers and Heisenberg, and the newer developments in quantum mechanics which have their root in Bohr's correspondence principle seem to offer a promising way of approach towards an understanding of the experimental results. But until we know much more than we do at present regarding the structure of molecules, and have sufficient quantitative experimental knowledge of the effect, it would be rash to suggest that they afford a complete explanation of it.

The Significance of the Effect

The universality of the phenomenon, the convenience of the experimental technique and the simplicity of the spectra obtained enable the effect to be used as an experimental aid to the solution of a wide range of problems in physics and chemistry. Indeed, it may be said that it is this fact which constitutes the principal significance of the effect. The frequency differences determined from the spectra, the width and character of the lines appearing in them, and the intensity and state of polarization of the scattered radiations enble us to obtain an insight into the ultimate structure of the scattering substance. As experimental research has shown, these features in the spectra are very definitely influenced by physical conditions, such as temperature and state of aggregation, by physico-chemical conditions, such as mixture, solution, molecular association and polymerization, and most essentially by chemical constitution. It follows that the new field of spectroscopy has practically unrestricted scope in the study of problems relating to the structure of matter. We may also hope that it will lead us to a fuller understanding of the nature of light, and of the interactions between matter and light.

Some Concluding Remarks

From a physical point of view, the quantitative study of the effect with the simplest molecules holds out the largest hope of fundamental advances. The beautiful work of McLennan with liquefied gases, and of R.W. Wood and Rasetti are pioneer investigations in this field which command the highest admiration. The quantitative study of the effect with crystals of the simplest possible chemical constitution is naturally of great importance. The case of the diamond, which has been investigated by Ramaswamy, Robertson, and Fox, and with especial completeness by Bhagavantam, is of special interest. Very surprising results have been

obtained with this substance, which may be the pathway to a fuller understanding of the nature of the crystalline state. I should also like to draw attention to the work of Krishnamurti, who has traced a remarkable dependence of the intensity of the spectral lines observed in scattering on the nature of the chemical bond, and followed the transition from the homopolar to the heteropolar type of chemical combination. Krishnamurti's observation that the paramagnetism of crystals apparently influences the observed intensity of the displaced lines is one of the most remarkable ever made in this new field of research.

Conversation between Mahatma Gandhi, C.V. Raman and Lady Raman : Bangalore, May 31, 1936

Raman and Charkha

The young men wanted Gandhiji to go to their Institute...If he listened to them, he would have to listen to many other requests, he argued in reply. Some of them wanted his autograph and had also thought of presenting him with a purse for Harijans.

GANDHIJI : I wish every one of you would want my autograph so as to swell that purse; but you must do all that where I am staying, but not drag me to the Institute.

The moment he was told that it was the Science Institute, he capitulated.

Of course, if it is the Science Institute you are talking of, I must make an exception in its favour, provided Sir C.V. Raman will show me some magic there.

He said to Lady Raman :

I have heard all kinds of good things about you from your husband, but I have to find out how far they are true. He told me the other day that whilst he is absorbed in his science, you find time for all kinds of humanitarian activities.

LADY RAMAN : Not as much as I should be doing. But I am certainly interested in khadi and Harijan welfare and social service and things of that kind. You know, Mahatmaji, I have been a spinner since many years ago. Some fifteen years ago I sent you a quantity of my own hand-spun yarn to be woven into cloth and the late Maganlal Gandhi sent the cloth on to me. But my husband had no faith in the wheel then. He would put away my wheel, smash it and break it; but I am glad to tell you that in my own life time the day has come when he no longer ridicules the wheel. He too believes in it.

I am very happy. Well, then, I want you to do a little work for me. Did you ever meet the late Kamala Nehru?

Once or twice, Mahatmaji, But I know the old Mrs Nehru very well.

But you of course know what a good woman Kamala was. You know how she spent herself for the country. But what I prize most of her is not her political contribution but her great spiritual beauty which I should like every man and woman to know.

Yes, I know of her services and her moral beauty.

Then you must help me in collecting some money for the Memorial we are having for her.

Lady Raman heartily agreed. As this business was going on, in came...Sir C.V. Raman. She was talking in Hindi as he came in. "Now, is that Hindi any good?" he asked jocularly.

Certainly as good as your science.

"Oh yes", spoke...Sir C.V. Raman, "she has an amazing capacity for picking up languages. She knows Hindi, she knows Bengali better than Hindi."

Of course, she has stayed in Calcutta for some years

"Not necessarily for that reason I, too, have stayed with her. But I know not a word. And now here she has picked up Kannada and talks it" Sir Chandrashekhara (Venkataraman) then began wondering what language could be the language for the masses of India and seemed for a moment to be inclined to the belief that English had the chance.

Don't you think it will be a bad day for the many millions of India who know Hindi without learning it to attempt to know English?

And Sir Chandrashekhara Venkataraman immediately said he was glad that Hindi was making rapid strides in South India and added : "I know Hindi too, Mahatmaji. I understand it very well. I learnt it from no less a teacher than Malaviyaji whose wonderful Hindi I had sometimes to hear for hours when I was in, Kashi, and I could not help learning it. But I cannot speak Hindi. It is that conceit you know, that I am full of as much as you."

Harijan, 6-6-1936

Mahatma Gandhi on All India Village Industries Association Wardha December 14, 1934

Object and Constitution

"As the idea was to form a Board of Administration of the policy and programme of the All-India Village Industries Association of persons who thoroughly believe in its policy and the practicability of its programme and who will, in effect, be whole-timers, both Mr. Kumarappa and I have given considerable time and thought to the formation of the Board.

It follows, therefore, that decentralization must be the keynote of the Board's policy, and India will be divided into as many areas as there may be workers or agents, who will work, organise and be responsible to the Board for the carrying out of its programme in their respective areas.

The workers or agents will be selected from those who consistently with their preoccupation of earning their livelihood, will give their whole time to the work of the Association. So far as possible, the agents will be honorary. They will collect what funds may be necessary for the organisation of their areas. It may be that the Board will not get many unpaid agents. It will be satisfied for a start, even with a few districts which are thoroughly organised and demonstrated to be economically and otherwise successful. A list of agents will be published from time to time.

The Board cannot carry on research work without the help of experts. And since experts cannot be expected to give their whole time and thought to the work of the Association. I have sent requests to several friends if they would allow their names to appear on the Board of Advisers. So far the following friends have kindly consented to be on it.

Dr. Rabindranath Tagore	Prof. Sam Higginbottom
Sir J.C. Bose	Dr. Jivraj Mehta
Sir P.C. Ray	Dr. M.A. Ansari
Sir C.V. Raman	Maj. Gen. Sir Robert McCarrison
Shri Ramdas Pantulu	Dr. Rajabally
Jamal Mohamed Sahib	V. Patel
Shri G.D. Birla	Dr. S. Subba Rao
Sir Purushottamdas Thakurdas	Dr. B.C. Roy
Sir S Pockhanawalla	Dr. Purushottam Patel

Wardha has been chosen as the Headquarters because of being centrally situated, being a junction station and being rather a glorified village than a city."

(From – The Collected Works of Mahatma Gandhi, The Publication, Division, New Delhi)

Albert Einstein : On Science and Truth

Einstein on Mahatma Gandhi

On the occasion of Gandhi's seventieth birthday in 1939. Published in Out of May Later Years, *New York : Philosophical Library, 1950.*

A leader of his people, unsupported by any outward authority : a politician whose success rests not upon craft nor the mastery of technical devices, but simply on the convincing power of his personality ; a victorious fighter who has always scorned the use of force; a man of wisdom and humility, armed with resolve and inflexible consistency, who has devoted all his strength to the uplifting of his people and the betterment of their lot; *a man who has confronted the brutality of Europe with the dignity of the simple human being, and thus at all times risen superior*

Generations to come, it may be, will scarce believe that such a one as this ever in flesh and blood walked upon this earth.

from *Ideas and Opinions* by Albert Einstein
(New York, Crown, 1954), 77-8

Message from Einstein for the Physics Laboratory of Delhi University (February 24, 1940)

"This is the sentence expressing my good wishes for your new Physics Laboratory :

Keep good comradeship and work with love and without pre-conceived ideas and you will be happy and successful in your work."

A. Einstein

Morality in our actions

The most important human endeavour is the striving for morality in our actions. Our inner balance and even our very existence depend on it. Only morality in our actions can give beauty and dignity to life.

To make this a living force and bring it to clear consciousness is perhaps the foremost task of education.

The foundation of morality should not be made dependent on myth nor tied to any authority lest doubt about the myth or about the legitimacy of the authority imperil the foundation of sound judgement and action. (1950).

from *Albert Einstein : The Human side*
edited by Helen Dukas and Banesh Hoffmann
(Princeton, Princeton University Press, 1979), 95

On Scientific Truth

I. It is difficult even to attach a precise meaning to the term "scientific truth." Thus the meaning of the word "truth" varies according to whether we deal with a fact of experience, a mathematical proposition, or a scientific theory. "Religious truth" conveys nothing clear to me at all.

II. Scientific research can reduce superstition by encouraging people to think and view things in terms of cause and effect. Certain it is that a conviction, akin to religious feeling, of the rationality or intelligibility of the world lies behind all scientific work of a higher order.

III. This firm belief, a belief bound up with deep feeling in a superior mind that reveals itself in the world of experience represents my conception of God. In common parlance this may be described as "pantheistic" (Spinoza).

IV. Denominational traditions I can only consider historically and psychologically; they have no other significance for me. (1929).

From *Ideas and Opinions by Albert Einstein*
(New York, Crown, 1954), 261-2

The most beautiful experience we can have is the mysterious. It is the fundamental emotion which stands at the cradle of true art and true science. Whoever does not know it and can no longer wonder, no longer marvel, is as good as dead, and his eyes are dimmed.

from *The World as I See It*,
by A. Einstein (Philosophical Library : New York, 1934)

I want to know how God created this world, I am not interested in this or that phenomenon, in the spectrum of this or that element. I want to know His thoughts, the rest are details.

in *Einstein : The Life and Times*,
by R.W. Clark (World Publishing : New York, 1971;
Hodder and Stoughton : London, 1979)

One thing I have learned in a long life : that all our science, measured against reality, is primitive and childlike—and yet it is the most precious thing we have.

Frontispiece to *Albert Einstein : Creator and Rebel*,
by Banesh Hoffman (Viking : New York, 1972;
Hart-Davis, MacGibbon : London, 1973; Paladin · London, 1977)

You imagine that I look back on my life's work with calm satisfaction. But from nearby it looks quite different. There is not a single concept of which I am convinced that it will stand firm, and I feel uncertain whether I am in general on the right track.. I don't want to be right.. I only want to know whether I am right.

From *Letters a Maurice Solovine*,
by Albert Einstein (Gauthier-Villars : Paris, 1956)

Advice to an Indian student

On 14 July 1953 an Indian in Delhi wrote Einstein a long and somewhat repetitious letter seeking aid. The gist of the letter was this : The writer was a bachelor, 32 years old, who wanted to spend the rest of his life doing nothing but research in mathematics and physics, although he was, admittedly, "terribly weak" in those subjects. He was penniless, as witness the fact that he was not placing stamps on the envelope of his letter Financial stringency in his young days had prevented him from acquiring a good foundation in science and mathematics although his interest in them was ardent. Family circumstances had obliged him to take a job to earn a living —something that was strongly against his inner nature. Fortunately, because of a small quarrel, he had been dismissed from his job more than a year before, and was thus free to pursue his true mission—but, alas, with no income at all to keep body and soul together. With or without help, he was determined to continue till he died, but, of course, life would be easier with financial aid, and he hoped that Einstein would help him.

On 28 July 1953 Einstein replied to him in English at some length in a letter that is interesting for more than just its courtesy ·

I received your letter and was impressed by your ardent wish to continue to study physics I must confess, however, that I can in no way agree with your attitude. We all are nourished and housed by the work of our fellow-men and we have to pay honestly for it not only by work chosen for the sake of our inner satisfaction but by work which, according to general opinion, serves them. Otherwise one becomes a parasite however modest our wants might be. This is the more so in your country

where the work of educated persons is doubly needed in this time of struggle for economic improvement.

This is one side of the matter. But there is another side to it which would have to be considered also in the case that you would have ample means to choose freely what to do. In striving to do scientific work the chance—even for very gifted persons—to achieve something of real value is very little, so that it would always be a great probability that you would feel frustrated when the age of optimal working capacity has passed.

There is only one way out : Give most of your time to some practical work as a teacher or in another field which agrees with your nature, and spend the rest of it for study. So you will be able, in any case, to lead a normal and harmonious life even without the special blessings of the Muses.

From *Albert Einstein : The Human side*
edited by Helen Dukas and Banesh Hoffmann
(Princeton, Princeton University Press, 1979), 58-9

In a Vision

Einstein became a legendary figure. Everybody knew his name, crowds thronged around him, and yet very few were actually able to understand the true nature of the revolution he had caused in science. The great physicist who presided over the meeting of the Royal Society declared "I must admit that up to the present moment no one has been able to tell me in simple words what Einstein's theory actually is." But the instinct of the masses is not always wrong. Einstein himself was the first one not to understand the immense fame which suddenly seized him. He was not however unconscious of the decisive progress he had just accomplished for the sake of human thought which had since millenniums tried to understand and explain the universe. When he said: for example : "It was an individual who discovered the cultivation of nutritious plants, it was an individual who discovered the steam engine," he spoke from experience. He, alone, had made such a discovery. Certainly he had men around him who had helped him, particularly mathematicians who patiently verified his calculations; but the essence of the research belonged to him alone. At times he felt as if he would never know if he would ever achieve his goal. One day he said to Alexander Moszkowski : "I would spend weeks in a state of complete confusion; and it was only with great difficulty that I overcame the stupor provoked by my first encounter with such questions." His son-in-law Marianogg reports the following conversation :

'Albert how is it that you came to make your discovery ?'

"'In a vision' he answered me."

"He told me that one day he had gone to bed in a state of discouragement so profound that no argument could put it to an end."

'When one reaches despair, nothing can help anymore, neither hours of work nor past success, nothing. All self-confidence disappears. It's over, I told myself, everything is useless. I haven't obtained any results......And that's when the thing came about.'

"With infinite precision, the universe and its secret unity of measure, structure, distance, time and space, such a monumental puzzle, was slowly reconstructed in Einstein's mind. And suddenly, as if printed by a giant printer, the immense map of the universe clearly unfolded itself in front of him in a dazzling vision. That is when he came to a sense of peace."

"Legend pretends that science is only for men of science, but as it is a part of truth *it must exist for everyone.*" In 1948, in the foreword to a book by Lincoln Barnett entitled *Einstein and the Universe*, he wrote, "It is of the greatest importance that the public at large has the opportunity of becoming aware—clearly and intelligently—of the efforts and results of scientific research. It isn't enough that a handful of specialists in each field attack a problem, sovle it and apply it. To reduce and limit the body of knowledge to a small group annihilates the philosophic spirit of a people and leads to the most serious spiritual poverty !"

from *Einstein* by Louis de Broglie *et al.*
(New York, Peebles, 1979), 20-2.

Erwin Schroedinger : What is Life? Epilogue
Cambridge University Press, 1944

On Determinism and Free Will

As a reward for the serious trouble I have taken to expound the purely scientific aspect of our problem *sine ira et studio*, I beg leave to add my own, necessarily subjective, view of the philosophical implications.

According to the evidence put forward in the preceding pages the space-time events in the body of a living being which correspond to the activity of its mind, to its self-conscious or any other actions, are (considering also their complex structure and the accepted statistical explanation of physico-chemistry) if not strictly deterministic at any rate statistico-deterministic. To the physicist I wish to emphasize that in my opinion, and contrary to the opinion upheld in some quarters, *quantum indeterminacy* plays no biologically relevant role in them, except perhaps by enhancing their purely accidental character in such events as meiosis, natural and X-ray-induced mutation and so on—and this is in any case obvious and well recognized.

For the sake of argument, let me regard this as a fact, as I believe every unbiased biologist would, if there were not the well-known, unpleasant feeling about 'declaring oneself to be a pure mechanism'. For it is deemed to contradict Free Will as warranted by direct introspection.

But immediate experiences in themselves, however various and desparate they be, are logically incapable of contradicting each other. So let us see whether we cannot draw the correct, non-contradictory conclusion from the following two premises :

(i) My body functions as a pure mechanism according to the Laws of Nature.

(ii) Yet I know, by incontrovertible direct experience, that I am directing its motions, of which I foresee the effects, that may be fateful and all-important, in which case I feel and take full responsibility for them.

The only possible inference from these two facts is, I think, that I—I in the widest meaning of the word, that is to say, every conscious mind that has ever said or felt 'I' —am the person, if any, who controls the 'motion of the atoms' according to the Laws of Nature.

Within a cultural milieu (*Kulturkreis*) where certain conceptions (which once had or still have a wider meaning amongst other peoples) have been limited and specialized, it is daring to give to this conclusion the simple wording that it requires. In Christian terminology to say: 'Hence I am God Almighty' sounds both blasphemous and lunatic. But please disregard these connotations for the moment and consider whether the above inference is not the closest a biologist can get to proving God and immortality at one stroke.

In itself, the insight is not new. The earliest records to my knowledge date back some 2,500 years or more. From the early great Upanishads the recognition ATHMAN = BRAHMAN (the personal self equals the omnipresent, all-comprehending eternal self) was in Indian thought considered, far from being blasphemous, to represent the quintessence of deepest insight into the happenings of the world. The striving of all the scholars of Vedanta was, after having learnt to pronounce with their lips, really to assimilate in their minds this grandest of all thoughts.

Again the mystics of many centuries, independently, yet in perfect harmony with each other (somewhat like the particles in an ideal gas) have described, each of them the unique experience of his or her in terms that can be condensed in the phrase: DEUS FACTUS SUM (I have become God).

To Western ideology the thought has remained a stranger, in spite of Schopenhauer and others who stood for it and in spite of those true lovers who, as they look into each other's eyes, become aware that their thought and their joy are *numerically* one – not merely similar or identical; but they, as a rule, are emotionally too busy to indulge in clear thinking, in which respect they very much resemble the mystic.

Life and Mind in the Universe

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Abstract

In my life as a scientist I have come upon two major problems which, though rooted in science, though they would occur in this form only to a scientist, project beyond science, and are I think ultimately insoluble as science. That is hardly to be wondered at, since one involves consciousness, the other cosmology. The consciousness problem was hardly avoidable by one who has spent most of his life studying mechanisms of vision. We have learned a lot, we hope to learn much more; but none of it touches or even points, however tentatively, in the direction of what it means *to see*. Our observations in human eyes and nervous systems and in those of frogs are basically much alike. I know that I see; but does a frog see? It reacts to light; so do cameras, garage doors, any number of photoelectric devices. But does it *see*? Is it aware that it is reacting? There is nothing I can do as a scientist to answer that question—no way that I can identify either the presence *or absence* of consciousness. I believe that to be a premanent condition that involves all sensation and perception. Consciousness seems to me to be wholly impervious to science. It does not lie as an indigestible element within science, but just the opposite: Science is the highly digestible element within consciousness, which includes science as a limited but beautifully definable territory within the much wider reality of whose existence we are conscious. The second problem involves the special properties of our Universe. Life seems increasingly to be part of the order of nature. We have good reason to believe that we find ourselves in a Universe permeated with life, in which life arises inevitably—given enough time—wherever the conditions exist that make it possible. Yet were any one of a number of the physical properties of our Universe otherwise—some of them basic, others seeming trivial, almost accidental—that life, which seems now to be so prevalent, would become impossible, here or anywhere. It takes no great imagination to conceive of other possible universes, each stable and workable in itself, yet lifeless. How is it that, with so many other apparent options, we are in a Universe that possesses just that peculiar nexus of properties that breeds life? It has occurred to me lately—I must confess with some shock at first to my scientific sensibilities—that both questions might be brought into some degree of congruence. This is with the assumption that mind, rather than emerging as a late outgrowth in the evolution of life, has existed always, as the matrix, the source and condition of physical reality—that the stuff of which physical reality is composed is mind-stuff. It is mind that has composed a physical Universe that breeds life, and so eventually evolves creatures that know and create: science-, art-, and technology-making animals. In them the universe begins to know itself. Also such creatures develop societies and cultures—institutions that present all the essential conditions for evolution by natural selection [variation, inheritance (mainly Lamarckian), competition for survival] so introducing an evolution of consciousness parallel with though independent of anatomical and physiological evolution.

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I have come to the end of my scientific life facing two great problems. Both are rooted in science; and I approach them as only a scientist would. Yet both I believe to be in essence unassimilable as science. That is scarcely to be wondered at, since one involves cosmology, the other consciousness.

I will begin with the cosmology.

I. A Universe That Breeds Life

We know that we live in a historical universe, one in which not only living organisms but stars and galaxies are born, mature, grow old, and die. There is good reason to believe that it is a universe permeated with life, in which life arises—given enough time—wherever the conditions exist that make it possible.

How many such places are there? I like Arthur Eddington's old formula : 10^{11} stars make a galaxy; 10^{11} galaxies make a universe. Our own galaxy, the Milky Way, contains about 10^{11} (one-hundred billion) stars; and the lowest estimate I have ever seen of the fraction of them that might possess a planet that could support life is 1%. That means one billion such places in our home galaxy; and with about one billion such galaxies within reach of our telescopes, the lowest estimate we might put to the number of places in the already observed universe that could support life would be of the order of one billion billion $- 10^{18}$.

And now, to the first problem : If any one of a considerable number of physical properties of the universe we know were other than it is—some of those properties basic, others seeming trivial, almost accidental—that life, that now appears so prevalent, would become impossible, here or anywhere.

I wish now to sample this argument, ascending meanwhile the scale of states of organization of matter.

A. Elementary Particles

Our universe is made of four kinds of elementary particle : neutrons, protons. electrons, and photons. I disregard neutrinos, since they do not interact with other

Aurobindo Center, New Delhi, January 8-10, 1979, in *The Evolution of Consciousness*, K. Gandhi, Ed (National Publishing House, New Delhi, 1983) pp 1-26; the 7th International Biophysics and 3rd Pam-American Biochemistry Congress, Mexico City, August 25, 1981 (Abstracts, p. 143); the International Seminar on the Living State, All-India Institute of Medical Sciences, New Delhi, December 13-19, 1981; the 20th Annual Orbis Scientiae (P.A.M. Dirac 80th Birthday Meeting). University of Miami Center for Theoretical Studies, January 17-22, 1983; and the Henri Bergson Symposium, University of Texas Medical Center at Galveston, February 10-11, 1984.

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matter; also the host of other particles that appear transiently in the course of high-energy nuclear interactions. The only important qualification one need make to such a simple statement is that the first three particles exist also as antiparticles, the particles constituting matter, the antiparticles antimatter. As we look out into space beyond our local cluster, we cannot really be sure whether what we see is made of matter or antimatter, since all such observations are made with radiation—photons—which do not discriminate, since they are, as we say, there own antiparticles.

One could start such a universe as this with neutrons, since neutrons—outside of atomic nuclei or neutron stars—are unstable, disintegrating within a half-life of about 10.6 min to protons, electrons and radiation, so supplying, with the residual neutrons, all the components of our present universe.

Why does the reaction go in this direction? Only because the neutron possesses about 8/10,000 greater mass than a proton plus an electron, and such a reaction necessarily goes in the direction of loss of mass. Suppose, as one easily can, that the reaction went the other way: that the neutron were that tiny amount *lighter* than a proton plus an electron. Then the protons and electrons of this universe would go to make neutrons; we should have a great dearth of those charged particles, hence the elements we know, the radiation that now fills our universe, and of course no life [2].

I should like now to raise two problems to do with protons and electrons, one involving their masses, the other their electric charge [3].

The nuclei of all elements beyond hydrogen are composed of protons and neutrons (hence nucleons), surrounded by orbiting electrons at distances relatively greater than separate the sun and planets. Both nucleons have masses about 1840 times that of the electron, so that virtually the whole mass of an atom is in its nucleus. Hence the nucleus is hardly disturbed at all by the motions of its electrons. So an atom can hold its position—really the position of its nucleus—in a molecule, and molecules their positions in larger structures. Only that circumstance permits molecules to hold their shapes, and solids to exist.

If on the contrary the elementary particles that compose atoms had more nearly equal masses, *light or heavy*, then motions by any one of them would be reflected in reciprocal motions by all the others. All structures composed of such atoms would be fluid. Could indeed such atoms form stable bonds ? In such a universe nothing would stay put. There could be no such fitting together of molecular shapes as permits not only crystals to form, but living organisms.

And now, electric charge : How does it come about that elementary particles so altogther different otherwise as the proton and electron possess the same numerical charge ? How is it that the proton is exactly as plus as the electron is minus ?

It may help to accept this as a legitimate scientific question to know that in 1959 two of our most distinguished astrophysicists, Lytttleton and Bondi, proposed that in fact the proton and electron differ in charge by the almost infinitesimal amount, $2 \times 10^{18}e$—two billion billionths e—in which e is the already tiny charge on either the proton or electron [4]. One's first thought is, what matter ?—but the authors explain that, given that very small difference in charge, all matter would be charged, and in the same sense, plus or minus. Hence all matter would repel all other matter, and the universe would expand, as it is assumed to do. The trouble is that, short of setting rather arbitrary boundary conditions, the universe would do little else. Even so small a difference in electric charge would be enough to overwhelm the forces of gravitation that bring matter together, and so we should have no planets, no stars, no galaxies—and no physicists.

No need to worry, however. Shortly after Lyttleton and Bondi's proposal, John King and his group at the Massachusetts Institute of Technology began to test experimentally whether the proton and electron differ in charge, and by 1978 had established that any such difference, if one exists at all, must lie under $10^{20}e$ [5]. The charges appear to be wholly identical.

To summarize : Only the slightly greater mass of the neutron drives it to decompose into a proton plus an electron, so keeping the universe supplied with these charged particles upon which the existence of atoms, molecules and radiation depend. If the proton and neutron did not have enormously greater mass than the electron, all matter would be fluid, and if the proton and electron did not possess exactly the same electric charge, no matter would aggregate. These are primary conditions for the existence of life in the universe.

B. Elements : H,O,N,C

Of the 92 natural elements, 99% of the living matter we know is composed of just four: hydrogen, oxygen, nitrogen, and carbon. That is bound to be true wherever life exists in the universe, for only those four elements possess the unique properties upon which life depends [6].

Their unique position in chemistry can be stated in a sentence : They—in the order given—are the smallest elements that achieve stable electronic configurations (*i.e.*, those mimicking the nearest inert gas, neon) by gaining respectively one, two, three, and four electrons. Gaining electrons, in the sense of sharing them with other atoms, is the mechanism of forming chemical bonds, hence molecules. The smallest elements make not only the tightest bonds, hence the most stable molecules, but introduce a unique property crucial for life. Of all the natural elements, only oxygen, nitrogen and carbon regularly form multiple covalent bonds—double and triple bonds—in which two and three pairs of electrons are simultaneously shared between two atoms.

Why is that crucial for life ? Consider two molecules that, since silicon lies just under carbon in the Periodic System of the elements, might be expected to have very similar properties : carbon dioxide and silicon dioxide. In carbon dioxide the central carbon is tied to the two oxygen atoms by double bonds O=C=O. That saturates completely the combining tendencies of all three atoms. Hence CO_2 is an independent molecule that goes off in the air as a gas, and dissolves in all the waters of the Earth, the places from which living organisms extract their carbon.

But silicon cannot form a double bond. Hence in silicon dioxide the central silicon makes only a single bond with each oxygen: —O—Si—O—, leaving four half-formed bonds—four unpaired electrons—two on the silicon and one on each oxygen, ready to pair with any other available lone electrons. But where find them ? Obviously on neighbouring SiO_2 molecules. Each SiO_2 binds to the next, and that to the next, and on and on until a huge supermolecule has formed, indeed a rock, for example quartz. The reason quartz is so hard is that to break it one must break chemical bonds. And that is why, though silicon is 135 times as plentiful as carbon in the Earth's surface, living organisms must be made of carbon. Comparable arguments can be made for oxygen and nitrogen.

Granted these elements are indispensable, how does the universe obtain them ? Only through a most extraordinary dispensation

The nascent universe consisted essentially only of hydrogen and helium, and these elements alone composed the first generation of main sequence stars. Such stars live by fusing hydrogen to helium, a nuclear reaction that goes at $(5\text{-}6) \times 10^6$ K. Four hydrogen nuclei (protons), each of mass 1, fuse to from a helium nucleus of mass about 4 · $4\,{}^{1}H \rightarrow {}^{4}He$ + 2 positrons + 2 neutrinos + gamma radiation.

But how go on to form the heavier elements ? One cannot just add the next hydrogen, for there is no stable atomic nucleus of mass 5. Then how about fusing helium nuclei ? That would require much higher temperatures, about 100×10^6 K, to produce collision velocities able to overcome the mutual repulsion of helium nuclei, each carrying four plus charges. To reach such temperatures the star must have left the main sequence, and begun to die as a red giant.

But also another barrier, for neither is there a stable atomic nucleus of mass 8. Two helium nuclei would fuse to make beryllium-8, which disintegrates within about 10^{-16}s. How, before that happens, add another helium to make carbon-12 ?

This situation is saved only by a strangely fortunate circumstance, the existence of a so-called *resonance*. Carbon-12 possesses an excited nuclear energy level just far enough above the combined energies of the beryllium-8 and helium-4 nuclei for the

difference to be made up by the energies of collision at the core of a red giant. This resonance virtually wipes out the barrier.

Even so, the fusion of helium to carbon goes very slowly, with a half-time of 10-100 million years (7). And even as the carbon forms, it could be removed again by adding two hydrogens to make nitrogen-14, or another helium to form oxygen-16. But—fortunately again—there is no further resonance to speed these reactions, so that carbon can maintain steady state levels close to those of nitrogen and oxygen (8).

Through such extraordinary circumstances the elements are produced that are needed for life. To make them, a first generation of stars had to begin to die as red giants. These spewed them into space, by distillation, in flares, novae, and supernovae. That made possible the formation of later generations of stars that contain these elements. We know that our sun is such a later-generation star because of life on the Earth.

C. Molecules . Water

By far the most important molecule for living organisms is water. I think we can feel sure that no liquid water, no life, anywhere in the universe. Water also happens to be the strangest molecule in all chemistry, and its strangest property is that *ice floats*. If ice did not float, I doubt that life would exist in the universe.

Virtually everything contracts on cooling. So does water, down to 4°C. But between 4 and 0°C, where it freezes, it expands, so rapidly that ice is less dense than liquid water, and floats. The complete hydrogen bonding among the water molecules in ice holds them more widely spaced than in liquid water, so ice floats.

What if water behaved like virtually everything else, and continued to contract on cooling? Then the increasingly dense water would constantly be sinking to the bottom. Freezing would begin, not as now at the top, but at the bottom; and would end by freezing the water solidly. A really large mass of ice takes very long to melt, even at higher temperatures. It is doubtful that life could arise subjected to such conditions, or having arisen, could survive, even were such an event to occur once in many millions of years.

As it is, water on freezing forms a skin of ice on its surface, that readily melts at warmer temperatures, and under which aquatic creatures, plant and animal, thrive throughout a period of cold.

D. Stars

It is as easy for a camel to pass through the eye of a needle as for a star to enter the kingdom of heaven. The needle's eye in this case is the fusion of two

hydrogen nuclei to deuterium plus a positron and a neutrino ($2^1H \rightarrow {}^2H + e^+ + \gamma$). That reaction takes 120 billion years, even under the conditions at the center of the Sun (2×10^7 K, density 80, 35% H) (9). It is the only reason why Main Sequence stars last as long as they do—hence long enough for life to arise and evolve on their planets.

The further reactions towards helium take negligible time; ${}^2H + {}^1H \rightarrow {}^3He$ takes 2 s; and ${}^3He + {}^1H \rightarrow {}^4He$, 0.2 s. Beginning with ${}^1H$, stars can live for billions of years; begining with deuterium they would yield only an explosion, as in a hydrogen bomb.

Why is the first reaction so slow? It is because though protons, bearing only unit positive charges, collide easily, they simply bounce apart again unless, to form a deuterium nucleus, one of them then and there becomes a neutron, which it can do by simultaneously adding an electron and expelling a neutrino. This is the only such reaction in the process, which is completed by two ${}^3He$ yielding ${}^4He$ plus two protons.

E. A Cosmic Condition

To have such a universe as this come out of the Big Bang requires an extraordinary balance between two great cosmic forces: that of dispersion (expansion). powered by the Big Bang, and that of aggregation, powered by gravitation. If gravitation were dominant, it would bring recession to a half, followed by collapse, either allowing insufficient time for life to arise and evolve, or all too soon destroying it. If on the contrary the forces of recession were dominant, that would yield an isotropically dispersed universe lacking local clusters, galaxies or planetary systems, hence providing no abodes for life.

The present universe displays a very close balance between these forces (10). Hence we find large-scale isotropy so that wherever an observer is stationed in the universe, it should look and behave about the same (the cosmological principle). This is combined, however, with local heterogeneity, local clusters of galaxies in which gravitation rules, as well as great spaces that seem to be utterly empty of astronomical bodies.

Our own relatively small cluster, called the Local Group, contains in addition to the Milky Way, the Andromeda galaxy (M31). Far from receding, it seems to be approaching our galaxy at about 125 miles/s, so accounting for the first astronomical spectral shift ever measured—for this reason a *blue shift* (Slipher, V. M. Lowell Obs. Bull. #58, 1913). One can observe the universal expansion only beyond our Local Group, that is, beyond a radius of about two million light years.

F. Summary

I have here only sampled briefly an argument that extends much further [11]. The nub of that argument is that our universe possesses a remarkably detailed

constellation of properties, as it happens just that constellation that breeds life. It takes no great intelligence or imagination to conceive of other universes, indeed any number of them, each of which might be stable and workable, yet lifeless.

How did it happen that, with what seem to be so many other options, our universe came out just as it did ? From our own self-centered point of view, that is the best way to make a universe: But what I want to know is, how did the universe find that out ?

It may be objected that the question would not arise if we were not here to ask it. Yet here we are, and strangely insistent on asking that kind of question.

Perhaps that indeed is the answer. That this is a life-breeding universe, precisely in order eventually to bring forth creatures that ask and attempt to answer such questions; so that through them the universe can come not only to be, but to be known; indeed can come to know itself. We are plunged at once into the deep ambiguities that exist between the concepts of *being* and *being known*; of which more below.*

II. Consciousness

The problem of consciousness was hardly to be avoided by one who has spent most of his scientific life working on mechanisms of vision. That is by now a very active field, with thousands of workers. We have learned a lot, and expect to learn much more; yet none of it touches or even points however tentatively in the direction of *what it means to see*.

When one examines the visual systems of human beings and frogs, they come out much alike. The retinas contain both rods and cones, the visual pigments are closely similar in chemistry and behaviour, the neural connections in the retina and with the brain are comparable. But I know that *I see*. I have good reason to believe that other persons see. Does a frog see ? It reacts to light, so does a photocell-activated garage door. But does it *see*, is it *aware* of visual images, does it *know* that it is responding ?

There is nothing whatever that I can do as a scientist to answer that question. That is the problem of consciousness. It is altogether impervious to scientific approach. As I worked on visual systems—it would have been the same for any other sensory mode, let alone more subtle or complex manifestations of mental activity—this realization lay always in the background. Now for me it is in the foreground. I think that it involves a permanent condition; that it never will become

* The properties that make this a life-breeding universe give it also a more general character. For if it were daprived of almost any of the properties that make life possible, it would become also a less variegated, less mutable, less innovative universe The breeding of life is one special manifestation of the more general *creative* quality.

possible to identify physically the presence *or absence* of consciousness, much less its content.*

The only unequivocally sure thing is what goes on in my own consciousness. Everything else that I think I know involves some degree of inference. As already said, I feel sure that other persons are conscious. It helps that they tell me so, and display other evidences of consciousness in speech and writing, art and technology. I believe that other mammals are conscious; and birds—why else would they sing? But frogs—and fishes? Those animals at least respond reasonably to light and some visual images. But I have worked also on the electrical responses to light of the numerous and anatomically magnificent eyes of scallops, without finding any indication that these animals see, beyond reacting to a passing shadow. And with some marine worms with great bulging eyes whose electrical responses we measured, we could find no behavioural responses to light at all [12].

The important point is that any assumption regarding the presence or absence of awareness in any nonhuman animal remains just that: an unsupported assumption [13]. Matters are no different with inorganic devices. Does the photoelectrically activated garage door resent having to open when a car's headlights shine on it? I think not. Does a computer that has just beaten a human opponent at chess feel elated? I believe not. But there is nothing I can do to shore up those assumptions either. (It will be objected that the chess-playing computer was programmed by a human chess player; but was not also its human opponent?)

Consciousness is not part of that universe of space and time, of observable and measurable quantities, that is amenable to scientific investigation. For a scientist, it would be a relief to dismiss it as unreal or irrelevant. I have heard distinguished scientists do both. In a discussion with the physicist P.W. Bridgman some years ago, he spoke of consciousness as "just a way of talking." His thesis was that only terms that can be defined operationally have meaning; and there are no operations that define consciousness. In the same discussion the psychologist B. F. Skinner dismissed consciousness as irrelevant to science, since confined to a private world, not accessible to others [14].

Unfortunately for such attitudes, consciousness is not just an epiphenomenon, a strange concomitant of our neural activity that we project onto physical reality. On the contrary, all that we know, including all our science, is in our consciousness. It is part, not of the superstructure, but of the foundations. No consciousness, no

* In this article I have used the terms ***mind*** and ***consciousness*** more loosely than I like, at times almost interchangeably. Others have done the same When I ask whether a frog—or a garage door—is conscious, I mean is it ***aware***, as we humans are aware. I speak also of consciousness—or better, mind—as a timeless and pervasive property, a complementary aspect of all reality, I hope that in each case the context will make my meaning clear,

science, public or private. Perhaps, indeed, no consciousness, no reality—of which more later.

Though consciousness is the essential condition for all science, science cannot deal with it. It does not lie as an unassimilable element within science, but just the opposite: science is the highly digestible element within consciousness, which includes science as a limited but highly definable territory within the much wider reality of whose existence we are conscious.

Yet within its own sphere, science is limitless. There it expands endlessly, every answer breeding new questions, facing in all directions and endlessly expanding horizon. It is the endless quest—for what? To bring more and more of the material world into our consciousness: to recognize, hence to become aware of, more and more subtle aspects of physical reality. That recognition is itself a kind of creation. Physical reality is not just "out there," waiting to be discovered. Its discovery in a sense creates it.

In my picture of these relationships, science stretches like a shoreless ocean, within the boundless space that is consciousness.

Consciousness itself lies outside the parameters of space and time that would make it accessible to science. That realization carries an enormous consequence; consciousness cannot be located. But more: *It has no location.*

Some years ago I talked about this with Wilder Penfield, the great Canadian neurosurgeon. In the course of his therapeutic activities he had unprecedented opportunities to explore the exposed brains of conscious patients, and hoped in this way to discover the seat of human consciousness. I asked him. "Why do you think consciousness is in the brain?" He chuckled, and said. "Well, I'll keep on trying." When we met again a few years later, he said. "I'll tell you one thing; it's not in the cerebral cortex!"

Shortly afterward came the exciting announcement that the so-called reticular formation in the brain stem of mammals contains an arousal center, a center that stimulates awareness. The dilemma involved in all such observations is that one cannot know whether one is dealing with a source, or with part of the machinery of reception and transmission. It is as though, finding that the removal of a transistor from a television set stopped the transmission, one concluded it to be the source of the program.

How could one possibly locate a phenomenon that one has no means of identifying—neither its presence nor absence—nor any known parameters of space, time, energy exchange, by which to characterize merely its occurrence, let alone its

content ? The very idea of a location of consciousness is absurd. Just as with Heisenberg's uncertainty principle, we have more to deal with here than technical inadequacy, with a perhaps temporary lack of means of observation and measurement. What we confront is an intrinsic condition of reality. It is not only that we are unable to locate consciousness : *It has no location.*

Consider pain, the most primitive of sensory responses, and most closely connected with survival. I have had to kill many animals in the course of my work, and have tried always to inflict a minimum of pain. But do other animals than man feel pain ? Many physiologists assert that only warm-blooded animals feel pain, and some of their publications have stated this as an official view. The National Eye Institute announced only in 1979 a first break with this position, asking workers with cold-blooded animals to try to avoid giving them "unnecessary pain." When I lop off the head of a frog, I assume that the headless body is beyond pain; but is the head ? So I hastily destroy the brain, and hope that ends the problem. Yet I have heard Wilder Penfield say that once a human brain has been exposed, one could operate on it with a spoon without causing an unanesthetized patient any great discomfort And what of a worm, any small piece of which wriths on being pinched ?

Recently there has been a controversy in the American press involving some physicians having asserted that a human fetus feels pain in an abortion. The very idea should raise deep concern about the very widespread American practice of circumcising male new borns, performed routinely without anesthesia, the physicians having assured the mothers that the nervous systems of their infants have not yet developed sufficiently for them to feel pain. All such assertions are equally groundless. Even as regards so primitive a concept as pain, we are altogether baffled in trying to substantiate its occurrence or absence.

I used to show students a film made by the French zoologist Fauré-Frémiet on the feeding behaviour of protozoa. Many of our sturdiest concepts of the apparatus required for animal behaviour are mocked by these animalcules, particularly by the ciliates; for in one cell they do everything; move about, react to stimuli, feed, digest, excrete, on occasion copulate, and reproduce. In this film one saw them encountering problems and solving them, much as would a mammal. I remember best a carnivorous protozoon tackling a microscopic bit of muscle. It took hold of the end of a fibril, and backed off at an angle, as though to tear it loose. When the fibril would not give, the protozoon came in again, then backed away at a new angle, worrying the fibril loose, much as a dog might have done, worrying loose a chunk of meat. It was hard, watching that single cell at work, not to anthropomorphize. Did it know what it was doing ?

But then, ciliate protozoa are the most complex cells we know. How about a cell highly specialized to perform a single function in a higher organism, a nerve cell for example, that can only transmit an impulse ? Once, years ago, I was visiting the invertebrate physiologist, Ladd Prosser, at the University of Illinois in Urbana. He took me into his laboratory where he was recording the electrical responses from a single nerve cell in the ventral nerve cord (that takes the place of our spinal cord) in a cockroach. It was set up to display the electrical potentials on an oscilloscope screen, and simultaneously to let them sound through a loud speaker. I was hearing a slow, rhythmic reverberation, coming to a peak, then falling off to silence, then starting again, each cycle a few seconds, like a breathing rhythm. Prosser remarked "That kind of response is typical of a dying nerve cell." "My God!" I said, "It's groaning! You've given it a voice, and it's groaning!" Was that nerve cell expressing a conscious distress ? Is something like that the source of a person's groaning ? There is no way whatever of knowing.

So that is the problem of mind—consciousness—a vast, uncharitable domain that includes all science, yet that science cannot deal with, has no way of approaching; not even to identify its presence *or absence*, that offers nothing to measure, and nothing to locate, since *it has no location.*

III. Mind and Matter

A few years ago it occurred to me—albeit with some shock to my scientific sensibilities—that my two problems, that of a life-breeding universe, and that of consciousness that can neither be identified nor located, might be brought together That would be with the thought that mind, rather than being as most biologists suppose, a late development in the evolution of organisms, had existed always: that this is a life-breeding universe because the constant presence of mind had made it so.

As I say, that came initially as a shocking idea, a bit of intellectual play, elating as a game is elating. But very quickly I realized that I was in excellent company. Not alone are rudiments of this kind of thought deeply embedded in millenia-old Eastern philosophies; it is stated explicitly or strongly implied in the writings of quite recent and some present physicists.

Perhaps being a biologist made it seem at first so strange to me. Biologists tend to be embarrassed by consciousness. As an attribute of some living organisms, they feel that they should know about it, and should indeed be in position to straighten out physicists about it—none of which has come their way. Hence the discomfort, the avoidance, or worse; talking ancillary mechanisms that dodge the essential problem. This is so plain as to have drawn comment from the physicist Eugene Wigner [15]

Whereas physicists live day in and out with the problem of consciousness. Early in this century it became evident to all physicists that the observer is an intrinsic component of every physical observation. Physical reality is what physicists recognize to be real. One cannot separate the recognition of existence from existence. As Erwin Schrödinger put it : "The world is a construct of our sensations, perceptions, memories. It is convenient to regard it as existing objectively on its own. But it certainly does not become manifest by its mere existence" [16].

A simple example of the intervention of mind in physical observation : Everyone by now is aware that radiation—light, indeed all elementary particles—exhibits two sets of what are essentially incompatible properties, those of waves and particles. This is the prime example of a widespread class of relationships that Neils Bohr brout together in his Principle of Complementarity. Enter consciousness: the physicist, setting up an experiment, decides beforehand which of those sets of properties he will encounter. If he does a wave experiment, he gets a wave answer; from a particle experiment he gets a particle answer.

Some years ago I began to entertain the thought that through the development of such science-making creatures as we, a universe wanting not only to be but to be known, can come to know itself: "Out of the ninety-two natural elements, four—C,N,O, and H—have unique properties that make life possible. Suppose, as one easily can, that they were less unique, more like the other elements. One wouldn't have to go far in that direction to make life impossible.

"Let me talk a little frank nonsense about this, make of it what you will. It would be a poor thing to be an atom in a universe without physicists. And physicists are made of atoms. A physicist is the atom's way of knowing about atoms"* [17].

Of course, implicit in such talk is the recognition that a universe in which mind can eventually achieve such overt expression as in science, art and technology must be at its core, from its inception, in some sense a knowing universe; that it must in some sense possess mind as its pervasive and enduring attribute. The stuff of this universe, then, is ultimately mind-stuff. What we recognize as the material universe, the universe of space and time and elementary particles and energies, is then an avatar, the materialization of primal mind. In that sense there is no waiting for consciousness to arise. It is there always. What we wait for in the evolution of life is only the culminating event, the emergence of creatures that in their self-awareness can *articulate* consciousness, can give it a voice and being also *social* creatures, can embody it in culture, in technology, art and science.

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* In this article, as in my thinking, I tend to speak of *physics* as any aspect of science that goes beyond simple description and classification. In that sense such aspects of biology become the physics of living organisms.

It is primarily physicists who in recent times have expressed most clearly and forthrightly this pervasive relationship between mind and matter, and indeed at times the primacy of mind. So Eddington (1928), "the stuff of the world is mind-stuff.. The mind-stuff is not spread in space and time...Recognizing that the physical world is entirely abstract and without 'actuality' apart from its linkage to consciousness, we restore consciousness to the fundamental position..." [18]. Von Weizsäcker (1971) states as "a new and, I feel, intelligible interpretation of quantum theory" what he calls his "Identity Hypothesis; Consciousness and matter are different aspects of the same reality." [19]. I prefer most of all Wolfgang Pauli's formulation (1952); "To us.. the only acceptable point of view appears to be the one that recognizes *both* sides of reality—the quantitative and the qualitative, the physical and the psychical—as compatible with each other, and can embrace them simultaneously... It would be most satisfactory of all if *physis* and *psyche* (*i.e.*, matter and mind) could be seen as complementary aspects of the same reality." [20].

What this kind of thought means essentially is that one has no more basis for considering the existence of matter without its complementary aspect of mind, than for asking that elementary particles not also be waves.

As for this seeming — at least until one gets used to it — a strange viewpoint for a scientist, I should like to say two things, first, that a fair number of major scientists have come to this conclusion. Perhaps all that is needed is to think deeply about it. And also, as in so many other instances, what is wanted is not so much an acceptable concept as an acceptable rhetoric.

If I say, with Eddington "To put the conclusion crudely — the stuff of the world is mind-stuff," that has a metaphysical ring. But if I say that ultimate reality is expressed in the solutions of the equations of quantum mechanics, quantum electrodynamics, and quantum field theory — that sounds like good, modern physics. Yet what are those equations, indeed what is mathematics, but mind-stuff? — virtually the ultimate in mind-stuff and for that reason deeply mysterious [15 (b)].

IV. The Evolution of Consciousness

I think that we now possesss, at least in outline, all that is needed to shape a credible view of the plan of this universe, and of the place in it of life and mind.

That view begins with a sense of the deep interpenetration of the concepts, *to be*, and *to be known*—existence, and its recognition.

Let us entertain the supposition that a universe that to be, needs to be known, to that end has taken on a design that breeds and fosters life so that life might eventually, here and there, evolve scientists who could cast back upon the history that produced

them, and could begin to understand it; through whose knowing, the universe could achieve increasingly the reality of becoming known, of coming to know itself.

Recently, to my surprise and that of some of the physicists most involved, this kind of thinking has been given the rather pretentious name: the anthropic principle. It states essentially that the universe possesses the properties it does in order eventually to produce physicists. Apart from meanderings in this direction, it emerged explicitly in a short paper by Dicke at Princeton, pointing out, for example, that the Hubble age of the universe is not wholly arbitrary, since about that much time was needed for physicists to appear [21]. I had enjoyed hearing this idea expressed some time earlier in the silly question, Why is the world 5—or 10 or 20—billion years old?—and the answer: Because it took that long to find that out!

But all of this, provocative as it is, does not yet express what I think is the crux of the matter.

A universe that through breeding life evolves eventually science-, art-, and technology-making creatures, presumably in many places, enters thereby a new phase in its evolution, that now includes means for the independent evolution of consciousness.

For such creatures found societies and establish cultures. They invent languages, writing, institutions for accumulating, storing and propagating information, speculation and belief.

Those creatures were evolved anatomically and physiolgically through natural selection, a process that involves three components: a ceaseless outpouring of inherited variations, advantageous and disadvantageous, a mechanism of inheritance; and a competition for survival, in the course of which those organisms and properties that function better are retained, and those that function less well are discarded.

Cultures —on our planet, human cultures—exhibit all these elements. They too display endless variations, both advantageous and disadvantageous to survival; mechanisms of *cultural* inheritance, mainly if not entirely Lamarckian (nongenic), since they involve almost entirely acquired (i. e., learned) characters, and continuous competition, an unceasing interplay of absorption and rejection, domination and subjection.

So is launched an independent evolution of consciousness, superimposed upon and parallel with the continuing evolution of anatomy and physiology. It takes its place as an intrinsic development in cosmic evolution. That universe in which, from its inception, matter and mind have been the complementary aspects of reality, now comes to develop, and regularly, in many places, complementary systems of evolution by natural selection, physical and mental.

I think that is the substantive outcome of our argument. It accords to humankind and its like elsewhere in the universe a great place in cosmic evolution. It gives our species here a transcendent worth and dignity, among the many kinds of creatures that inhabit our planet. It tells us our place in the universe; it is to know and create, and to try to understand, as we alone can do under our sun.

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Bicycling about to be explained ?

A new calculation seems to have made the behaviour of bicyclists explicable — but there is a long way to go before the matter will be satisfactorily understood.

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The essential problem of the bicycle — why does a moving bicycle not tip over more often ? — may at last have been solved.

That at least is the implication of a report by G. Franke, W. Suhr and F. Riess from the University of Oldenburg (*Eur J. Phys.* **11**, 116; 1990). But one should be cautious. In the long history of mechanics, claims that the problem of the bicycle has been solved have been regularly followed by demonstrations that the claims are based on over simple approximations that invalidate the conclusions. Ominously even Franke and his colleagues have simplified the problem by supposing that the rider steers the bicycle only by adjustments of the position of his or her centre of gravity. It is hands-off riding. On the face of things, the solution does not accommodate what common observation demonstrates — that riders pedalling find it advantageous to make energetic movements from side to side while playing with the direction of the front wheel.

Franke and his colleagues are forgiving about previous attempts at the problem, which they acknowledge to be difficult.

They also take note of earlier demonstrations that one of the crucial determinants of stability is the distance between the axis of the steering column and the centre of the front (steerable) wheel, called the 'trail length' in the argot of the discipline. This is why the front fork of a bicycle, the device that supports the steering mechanism and the front of the bicycle frame on the front wheel, is usually bent forward towards the bottom. Their objective is to solve the problem of the moving bicycle with as few limitations as they can manage. Among other things, for example, they have allowed for wheels of unequal radius, which means that their solution should be as easily applicable to penny-farthings as to modern designs.

Much of the interest in the new attempt at the problem is the manner in which the authors have formulated it. At least superficially, it is not as complicated as might be expected.

Crudely, if a bicycle (with its rider) were a rigid body, it would have six degrees of freedom (three translation degrees of freedom and three rotations).

But bicycles are not rigid; the front wheel can be steered (through a 'steering angle') while the two wheels can rotate. So there are nine degrees of freedom altogether — six intrinsic to a rigid body and three strictly internal degrees of freedom. The configuration of the bicycle at any time could in principle be defined by specifying nine variables. If the bicycle is moving, for each degree of freedom there will be a coordinate in a suitably chosen reference frame and a corresponding velocity.

But it is clear that not all possible motions correspond to stable reality. To achieve that, the two wheels, for example, must remain in contact with the ground. So the problem of the moving bicycle is that of the motion of a rigid body which is subject to what are called constraints. The simplest way of dealing with such problems is to choose a set of coordinates that, will automatically ensure that the constraints are satisfied, which sometimes requires a little ingenuity.

But Franke and his colleagues make the task seem simple. Of the nine configurational degrees of freedom, for example, two are eliminated by the requirement that the wheels should be on the ground, while —at least on level ground—neither the absolute degree of rotation of the two wheels nor the absolute position and direction of the frame can be relevant to stability.

The result is that the configuration of a bicycle can be described by only two variables, taken as the steering angle and the lean angle. On course, the dimensions of the actual bicycle enter as parameters—Franke and his colleagues use the radii of the two wheels, the trail length, the distance along the perpendicular between the centre of the rear wheel and the steering axis and the distance between the centre of the front wheel and that same perpendicular as the parameters that specify the bicycle. By similar arguments, the dynamical degrees of freedom are reduced to three — the time derivates of the steer angle and the lean angle and the scalar velocity of the bicycle (measured, for the sake of definiteness, at the rear wheel)

Turning this description of a moving bicycle into a set of equations of motion that might be solved is the more tricky part of the calculation. For practical purposes, the authors used a moving system of rectangular coordinates whose origin is the point at which the steering axis meets the ground, but whose unit vectors are along the direction of motion of the rear wheel, along the point of contact at the rear wheel with the ground to its centre and towards the hub of the rear wheel. (The last choice leads to the convenient result.that the lean angle does not appear in the equations of motion). Even so, the outcome is a vector equation (equivalent to three simultaneous scalar equations) that cannot be solved analytically, only numerically. No doubt these equations will soon be known by heart in the places at which bicycles are designed; they are a potentially endless resource for bicycle-makers.

The immediate benefits of the investigation, unfortunately, are more a spur to further investigation than a revelation in themselves. Franke and his colleagues have

allowed for the bicycle rider to adjust his position laterally relative to frame. The rider's weight is supposed to be an unladylike 70kg. One set of solutions to the equations of motions arises by supposing that a no-hands bicyclist of this size travels in a repeating circle, with a constant steering angle and a constant velocity.

Indeed as one would expect, the greater the lean angle, the greater must be the steering angle (for a fixed velocity) or the greater the velocity (for a fixed steering angle). It is more surprising that while, above a certain critical velocity, there should be only one combination of steering angle and rider displacement that will keep the bicycle travelling in a circle at a prescribed lean angle, below that critical speed, there are two lean angles at which the same rider displacement will keep the bicycle in a circle. Those who ask whether this is a sign of incipient bifurcation to chaos will not be surprised to be answered in the affirmative.

Perhaps the most practical implication of the calculations so far carried out is that the speed at which circular motion can be stable is sensitively dependent on the moment of inertia of the wheels: the smaller the combined moment of inertia, the greater must be the velocity. Similarly, the trailing distance crucially determines the range of velocities over which motion in a circle can be stable; the greater the forward displacement of the front wheel, the greater the range of stable velocity. That of course, is what all circus bicycle-riders know by instinct.

What all this means for real bicycle-riders is hard to tell. That the forward displacement of the rider's centre of gravity is the equivalent of lengthening the trailing distance is unsurprising.

This, no doubt, is why riders stand on the pedals when going very slowly. But what the new equations of motion mean for the behaviour of bicycle-riders remains to be determined.

John Maddox

MEGHNAD SAHA MEDAL LECTURE-1978*

ATOM AND SELF

D.S. KOTHARI, F.N.A.

(Delivered on 5 October 1979)

THE name of Meghnad Saha will always remain associated with the theory of thermal ionization. If a theory is to be judged by the simplicity of its concepts and the fertility of its applications, then Saha's contribution would count as one of the greatest of the present century.

I. Life of Saha

Saha was born on 6th October, 1893 in Seoratali village in the district of Dacca (now in Bangladesh). He died on 16th February 1956. Saha came from a family with very meagre means. His early education was beset with great hardships. In 1905, the year of great political unrest in Bengal, Saha was involved in a boycott of the visit of the British Governor to his school. He had to leave the school and forfeit the Government scholarship awarded to him for standing first at the middle school examination. He joined a private school, and passed the Entrance Examination of the Calcutta University in 1909, standing first amongst the East Bengal candidates. Saha was a precocious student. He joined the Calcutta Presidency College in 1911. Here his teachers were Acharya P.C. Ray, J.C. Bose, D.N. Malik and C.E. Cullis. Both in the B.Sc. (1913) and the M.Sc. (1915) in Applied Mathematics examinations, Saha had the second place, the first position going to S.N. Bose. He thought of competing for the Indian Finance Service, the only All India Service open to an Indian at the time, but was refused permission by the Government. To support himself and his younger brother, Saha took to private tuitions covering long distances on a bicycle. In 1916, he was appointed Lecturer in the Mathematics Department of the newly founded University College of Science (Calcutta) for post-graduate education and research. A year later, both he and S.N. Bose were transferred from the Mathematics Deparment to the Department of Physics. The following year, C.V. Raman, leaving the Indian Finance Service, joined as the Palit Professor of Physics. Several of the postgraduate courses Saha had to teach were entirely new to him. He had studied physics upto the B.Sc. only. Saha found thermodynamics and spectroscopy especially stimulating. Fortunately—as he often used to recall in later life—about this time he came across Miss Agnes Clarke's two excellent popular books on the sun and the stars. These books fascinated him

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greatly and gave him some idea of the main problems in astrophysics. He was familiar with Planck's book on *Thermodynamics*, and papers of Böhr and of Sommerfeld on the quantum theory of the atom. This prepared the way for his epochal work (cf. Kothari, 1960).

In Saha's own words: "It was while pondering over the problems of astrophysics, and teaching thermodynamics and spectroscopy to the M.Sc. classes that the theory of thermal ionization took a definite shape in my mind in 1919. I was a regular reader of German journals which had just started coming after four years of First World War, and in course of these studies, I came across a paper by J. Eggert in the *Physikalische Zeitschrift*, Dec. 1919, "*Uber den Dissoziationzustand der Fixsterngase*" in which he applied Nernst's Heat Theorem to explain the high ionization in stars due to high temperatures, postulated by Eddington in course of his studies on stellar structures.

"Eggert, who was a pupil of Nernst and was at the time his assistant, had given a formula for thermal ionization, but it is rather strange that he missed the significance of ionization potential of atoms, importance of which was apparent from the theoretical work of Böhr, and practical work of Franck and Hertz which was attracting a good deal of attention in those days. Eggert used Sackur's formula of the chemical constant for calculating that of the electron, but in trying to account for multiple ionization of iron atoms in the interior of stars on this basis, he used very artificial values of ionization potential.

"While reading Eggert's paper, I saw at once the importance of introducing the value of 'ionization potential' in the formula of Eggert, for calculating accurately the ionization, single or multiple, of any particular element under any combination of temperature and pressure.

"I thus arrived at the formula which now goes by my name. Owing to my previous acquaintance with chromospheric and stellar problems, I could at once see its application. I prepared in the course of six months of 1919 (February to September) four papers and communicated them for publication in the *Philosophical Magazine* from India within August to September."

Notice how remarkably forthright, so characteristic of him, is this description. The discovery looks so simple, almost inevitable. That is the feature of a fundamental discovery. Think for a moment of the de Broglie relation. Any serious undergraduate student of physics could have written it down. The relation is so amazingly obvious. That is why it had to wait for the genius of a de Broglie.

In his introduction to the well-known treatise on *Theoretical Astrophysics* (1936), S. Roseland observes : "Although Böhr must thus be considered the pioneer

in the field, it was the Indian Physicist, Meghnad Saha who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory. The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the subsequent work has the character of refinements of Saha's ideas."

The equation that goes by Saha's name first appeared in the *Philosophical Magazine* of Oct. 1920. The work, it should be remembered, was done in Calcutta, before Saha went to Europe for two years. Abroad, he worked with A. Fowler (London) and W. Nernst (Berlin). In 1921, he returned to Calcutta. In 1923, he joined the University of Allahabad. Here he stayed for 15 years. He gave a major part of his time to teaching undergraduate and postgraduate classes. The lectures were carefully prepared, and a good part of what he spoke he wrote on blackboard in his clear and bold handwriting. He made copious use of lantern slide. He was fond of demonstration experiments. In 1938, he returned to the University of Calcutta where he remained till his death in 1956.

Saha's role was of the utmost importance in establishing the Institute of Nuclear Physics in Calcutta, in building the laboratories of the Indian Association for the Cultivation of Science, and in founding Academies of Sciences in India. He was the Second President (1937-1938) of our Academy. He, more than any one else, was responsible in starting the monthly journal *Science and Culture*, and he was its Editor for many years. He was from the beginning, a member of the Council of Scientific and Industrial Research constituted by the Government in 1942, and member (or chairman) of several of the research and other committees of the Council. He was the Chairman of the Council's Indian Calendar Reform Committee. He was elected an independent member to the Parliament in 1951. He took the keenest interest in problems of national planning, particularly in relation to science and industry. He was an active member of the National Planning Committee appointed by the Indian National Congress in 1938 with Jawaharlal Nehru as Chairman.

The life of Saha was an integral part of the great scientific renaissance in our country to which he contributed so magnificently and in an extraordinarily wide variety of ways. He was extremely simple and austere in his habits; and though almost unmindful of his personal needs, he was most solicitous in the case of others. He was a man of undaunted spirit and compassion, resolute determination and dedication.

Saha's philosophy of socio-economic development and planning is perhaps best expressed in the following words from his article in *Nature* (1945). "The philosophy of kindliness and service to our fellow-men was preached by all founders of great religions, and no doubt some great kings and ministers of religions in every country

and at all ages tried to give effect to this (altruistic) philosophy. But the efforts were not successful, for the simple reason that the methods of production of commodities were too inefficient to yield plenty for all, which is an indispensable condition for practical altruism. We can, therefore, hold that *so far as individual life is concerned*. science has achieved a target, 'aimed at by the great founders of religions, in advanced countries of the world. The effects of maldistribution of wealth, due to historical causes. are being rapidly cured by the introduction of social laws."

For man's progress and alleviation of suffering we need *both* science and "philosophy of kindliness...preached by all...religions."

II. Association with Saha

My life-long association with Saha, deepening with years, began in 1924 as a first year undergraduate student at Allahabad. What higher good fortune there can be than to come in intimate contact with a truly great man ! And such a one was Meghnad Saha. I owe more to him than I can express, even indicate, in words.

One day in the evening in 1927—in the month of December—Saha came to my room in the Jain Hostel, and wanted me to accompany him on his evening walk. Brisk walk for an hour or so in the morning and evening was usual for him. He enquired if I intended to appear at the competitive examinations for the Government Services. I had no such idea. This pleased him greatly. He asked if I would accept a demonstratorship likely to fall vacant in July that year (1928). I was overjoyed. Next day, he dictated to me an application which I submitted; and in July (after the M.Sc. results were out), I received an appointment letter from the University. Again, how well I remember that I would have returned from Cambridge (Cavendish Laboratory) without a degree for I thought, rather naively, that it was better to devote time to learn new physics and mathematics from the great masters than to work within narrow limits for a Ph.D.* That this did not happen, I owe to Saha's compelling advice. He wrote to me (1932) that to return without a degree would be to jeopardize my pursuit of physics in India. I needed extension of my two-year U.P. Government Scholarship by six months. It was done on the recommendation of the Master of my College as he was at the time a member of the British Parliament. An earlier request strongly supported by Lord Rutherford had been abruptly rejected. Again it was Saha who insisted, and almost forced me, to leave Allahabad in 1934 to join the University of Delhi where a readership had fallen vacant. The physics teaching in Delhi then was limited to the B.Sc. degree only. There were only two teachers, myself and a demonstrator. There were no postgraduate courses in science subjects. That was the situation in the capital of our

* The High Commission Office (London) had fixed my admission to Oxford against my wishes. It was a confluence of 'lucky coincidences' that got me to the Cavendish Laboratory. [May be, a case of "synchronicity" see Section XI]

country till the early 1940's (Saha wanted me to leave Allahabad for he was unhappy that the University had not agreed to accept his recommendation for salary increments in demonstrator's grade for the period I was away at Cambridge.)

At Allahabad, Saha created a great School of theoretical physics. Many names of dear friends immediately come to my mind; and of course, R.C. Majumdar from whom I benefitted greatly. On quite a few occassions, I copied articles for Saha for publication. (There was no typist in the department).

III. Atom and Self

Saha felt that for a physicist, it was not enough to learn only physics and mathematics. Some acquaintance with history of science and with philosophy was necessary. He gave me, in my student years, to read, amongst other books, Oliver Lodge's *Pioneers of Science* and Will Durant's *Story of Philosophy*, and *Mansions of Philosophy*. My regret, therefore, is all the more that I did not, at any time, discuss with Saha what his views, and his beliefs, were on fundamental questions such as the problem of mind-body interaction. It never occurred to me to ask him such questions, strange as it may seem. Also, it did not occur to me to ask what was the 'happiest' thought of his life, and the 'saddest' thought Most people, except the highly creative, would find it very difficult to identify a single thought as the 'happiest' of their life. [For Einstein, the 'happiest thought' of his life came in 1907 at the age of 28, as he has himself recorded. It was the thought that "the gravitational field has similarly (like the electric field produced by electromagnetic induction) a *relative* existence. For, if one considers an observer in free fall, e.g., from the roof of a house there exists for him during his fall no gravitational field at least in his immediate vicinity," (G. Holton, *The Physics Teacher*, March 1979)].

Why did I not ask Saha his views on 'self'? I have no answer. I really do not know. May be, because, I did not realize then, as in some measure I do now, that there is no profounder problem, nor more fundamental and more puzzling, than the interaction between 'atom' and 'self'. Another name for it is the brain-mind or body-soul problem**.

If we use word such as 'soul', we should not mix this profound concept with naive, puerile descriptions which contradict Science or reason To do is to kill the concept right at the start. This is emphasized forcefully in the *Upanishads* and the *Gita*.

The awareness—for me—of the brain-mind-problem is largely a result of renewed interest amongst physicists in the foundations of quantum mechanics, and the writings of Sherrington, Schröedinger, Wigner, Eccles, and Proper—to mention some

**Unfortunately, I did not come across books on Indian philosophy except very much later

names which immediately come to my mind. But what an irony! At a time when ever the remotest idea that there was a problem of the 'self' did not strike most people doing physics in the homeland of the *Upanishads*, there was Schröedinger, in distant Berlin, writing an Essay in 1925, on the *Vedanta*. And this at the very same time he was fully absorbed in the discovery of the epoch-making wave-equation for the electron. How formidable is the gap between Indian higher education and our philosophical-ethical thought!

In an oft-quoted statement (1951) Schröedinger says : "I consider science an integrating part of our endeavour to answer the one great philosophical question which embraces all others, the one that Plotinus expressed by his brief : *who are we?*. And more than that : I consider this not one of the tasks, but *the* task of science, the only one that really counts."

In other words, the ultimate goal of science and of all moral and spiritual striving is the same. There is no difference. *'Who am I?'* is what Nachiketas asks in the *Katha Upanishad.* The question '*Who am I?*' is, on close analysis, no different from the question what is the abode of *Truth?* Does *Truth* reside in space and time or is it outside both space and time? More about this later. Many may not go far as Schroedinger. But all would agree that the grave dangers facing mankind today—think of the mounting probability of an all-out nuclear war—cannot be met unless earnest attention is paid to an understanding of the self, the human being.'

The search for 'who am I?' is the foundation of all true morality and religion. 'what is an electron?' is a question which relates to the external world. 'Who am I?' belongs to the internal world.

Mankind's very survival is at stake†. That we need to know more about the atom, about the external world of space-time and matter-energy, is beyond question. But to ignore altogether the knowledge of the self can in the end only invite disaster. The foundation of duty and reverence is self-knowledge, and not the atom, not the external world. Even to decide to dedicate onself to Science, this decision, is not a part of science. It is outside science. It is akin to some kind of religious faith. It is, perhaps, no exaggeration when E.F. Schumachar (1977) says : *"The modern experiment to live without religion has failed* (italics his), and once we have understood this we know what our 'post-modern' tasks really are?" A.N. Whitehead said some years ago that the future of civilisation depends on the degree to which we can balance the forces of science and religion. And in describing the aims of education, he tells

†As the SIPRI Yearbook (1978) points out the total explosive power of nuclear weapons in the World's arsenals is equivalent to about one *million* Hiroshima-type atomic bombs. Even if a significant fraction of these weapons were used, most of the cities in the Northern Hemisphere would be destroyed utterly; and the genetic damage may decimate the human species itself.

us that the essence of education is "it is religious.. which inculcates duty and reverence." (A.N. Whitehead, *Aims of Education*, 1962).

It has been my belief from student days (ever since I read the *Gita*, Annie Besant's translation) that foundations of relativity and quantum theory provide highly suggestive analogies and ideas for an appreciation and understanding of Indian spiritual thought. This has been, of course, immensely reinforced by the inspiring writings of Einstein, Böhr, Schröedinger, Heisenberg, Wigner and others. Also, for a quest of the *foundations* of modern physics, Indian philosophic thought can be very stimulating and suggestive. No longer can the problems of the *nature of reality* be evaded in physics. An occasion to speak on '*Atom and Self*' has therefore, for me a special interest.

IV. Two Realities

Two things are important. Firstly, *the duality of the two worlds*, and secondly, *the question of interaction between them.* The 'external world' and the 'internal world', that is to say the 'atom' and the 'self' should be accepted as equally significant for human life, the two equally real. Cyril Hinshewood (1962) observes: "To deny the reality of the inner world is a flat negation of all that is immediate in existence: to minimise its significance is to depreciate the very purpose of living, and to explain it away as a product of natural selection is a plain fallacy."

The external world (E-World) is public, *objective.* The E-World includes of course, the body. The internal world (I-World) is the world of the *psyche* — 'I' self, spirit, soul, mind, or whatever we may call it. It is private, *subjective.* Thoughts, feelings, emotions, pleasure and pain, purpose, goals, all these belong to the I-World. Psychology, to the extent that it investigates the I-World by methods appropriate for the E-World, can be called science, strictly speaking. But then it is hardly a study of the I-World. The amazing reliability and strength of science lies in its *objectivity.* Within science there is no place whatsoever for questions such as : to what purpose?, to what ends or goals?, why the starry sky is beautiful? These are moral questions. These are not questions *within* science. *The exclusion of subjectivity, that is "I", from natural science is total.* This has come about gradually since the time of Galileo and Newton. *Brain* belongs to the E-World, *mind* or *consciousness* belongs to the I-World.

If we insist on holding one of the two, the external world (Matter) and internal world (Mind), as the only reality, or the one as the more fundamental of the two, two options are open to us. We may take matter *above* mind, or mind, *above* matter. The choice is not at all an easy one. We may be inclined to believe that matter is primary, and mind an appearance, an epiphenomenon, of matter. It accords with the usual presentation of the theory (or rather the doctrine) of the Darwinian organic evolution. But then there is this difficulty. The *belief* itself that mind is an 'appear-

ance' of matter belongs to the mind. This belief, therefore, can be no more than an appearance. It loses its reliability, its reality. Recall Hinshelwood's statement quoted earlier. If then a choice has to be made at all, it seems preferable to take mind as the primary reality, and matter as secondary : *chetan* as primary and *jada* as secondary. This is in keeping with the teachings of the great *Upanishads* which emphatically declare the primacy of *chetan*. *Everything that exists is either chetan or for the chetan (mind)* [see. e.g., Hiriyanna (1973)]. The very idea of something existing implies the existence before hand of an entity to which the idea can belong. In recent years, strong support for the primacy of the *chetan* has come from a totally unexpected quarter. Many scientists, notably theoretical physicists such as Schrödinger and Wigner, hold mind as distinct from the brain, the primary reality. Wigner (1964) says : "There are two kinds of reality or existence—the existence of my consciousness and the reality or existence of everything else. This later reality is not absolute, but only relative. Excepting immediate sensations, the content of my consciousness, everything is a construct; but some constructs are closer, some farther, from the direct sensations."

The views about the primacy or otherwise of mind, by their very nature, are not a part of physics, not within physics. These go beyond physics. To say 'beyond-physics,' is not to imply anti-physics, or contradiction of physics. Not at all. Antiphysics, or antiscience, should be ruthlessly denied any place whatsoever in human thought and affairs. One must remember the distinction clear in principle even if in practice it be difficult to apply, between *anti-physics*, *physics* and *beyond-physics*.

It is of the utmost importance to grasp the foundamental distinction between 'atom' and 'self' or, what comes to the same thing, between brain and mind. Atom or brain belongs to the external, objective world of space-time and matter-energy. Self or mind belongs to the internal subjective world. The subjective (mental) world, is not describable in terms of space-time and matter-energy concepts. *Self or mind, therefore, lies outside natural science*. When I say that the self is outside the domain of space-time many great recent writings which lucidly and convincingly expound the theme immediately come to mind. For example, Sherrington (1940); Schrödinger (1958); Penfield (1975), Greidanus (1975) Popper and Eccles (1977) and Wheeler (1977).

(Notice that the title of the great book by Popper and Eccles is *The self and its Brain* and *not* The Brain and its Self).

Let me content myself with one quotation from Penfield. He writes (1975) : "Throughout my scientific career, I, like other scientists, have struggled to prove that the brain accounts for the mind. But now, perhaps, the time has come when we may profitably consider the evidence as it stands, and ask the question : *Do brain mechanisms account for the mind?* And he concludes : "Because it seems to me certain

that it will always be quite impossible to explain the mind on the basis of neuronal action within the brain, and because it seems to me that the mind develops and matures independently throughout an individual's life as though it were a continuing element...I am forced to choose the proposition that our being is to be explained on the basis of two fundamental elements." It reminds us forcefully of the *Sankhya Darshan;* and specially the *Sankhya Karika* of Ishwarkrishna, a fifth century text and a psycho-physical classic of all time.

As the brain is *within* natural science and the mind outside natural science, the problem of comprehending the brain-mind interaction becomes the riddle of riddles—the greatest mystery of all. What little light modern physics can throw on the problem we shall consider presently. In passing, we may note a suggestive analogy between atom and self. When an atom makes a transition, or a 'jump', from one stationary state to another the actual process cannot be visualised or even imagined. There are no intermediate stages. We cannot breakdown the process into its components : The entire process of transition from one state to another is a non-visualisable, unanalysable, unity. *It is indivisible.* Its parts cannot even be imagined. It is a 'quantum jump', as we call it. The interesting thing is that there is an analogous situation for *thought processes.* As we 'think'— in any sequence of thoughts—there is always a sudden, discontinuous jump from one thought to the next. We are not aware at all of any intermediate stages. If we were so aware, no thinking would be possible. There would be an almost infinite sequence of 'sub-thoughts' between two thoughts, like an infinity of points between the two ends of a line. *Quantum Jumps for thoughts appear to be as much a necessity for the conscious self as these are for the atom.* This analogy between the self and the atom—*and it is no more than an analogy*—suggests some interesting possibilities for the mind, but these will not be pursued here.

V. Quest for Inner World

Einstein remarked that "the most incomprehensible thing about the universe is that it is comprehensible." Perhaps, even more incomprehensible it is that one mind can comprehend another mind, though the two are totally isolated, separate from one another. How does it become possible that we understand one another, at any rate in some measure, whether we talk about the external world or about ourselves? Is it that in reality there are not many minds, but only *One Mind?* This is the assertion of Vedanta. There is a penetrating discussion of the problem by Schröedinger in *My view of the World* (1964). This remarkable book, of no more than 29,000 words, and which for Schröedinger was "really the fulfilment of a very long cherished wish," contains two essays : one, *Seek for the Road,* was written in 1925, the year of his fundamental discovery of wave mechanics, and the other *What is Real?,* was written in 1960. *Seek for the Road* is an enquiry into '*who am I?*' Schröedinger, fully occupied in 1925 in elucidating the wave nature of the electron, is responding, as it were, to

the reciprocal question of the electron : "*who are you to know me?*" May be, his deep pre-occupation at the time with both the electron and the psyche led him to the symbol *psi* for the electron wavefunction rather than *phi* for it (Greek *Phusis* = Nature). The two essays were published for the first time in 1961. Why this long waiting to publish the 1925-essay? Perhaps (as he says), the thoughts expressed were far too strange, far too daring—at any rate for the Western World—to be published but in old age. Schrödinger writes : "A hundred years ago, perhaps, another man sat on this spot; .. Like you he was begotten of man and born of woman. He felt pain and brief joy as you do. *Was* he someone else? Was it not you yourself? What is this self of yours?. What clearly intelligible *scientific* meaning can this 'someone else' really have?.. Looking and thinking in that manner you may suddenly come to see, in a flash, the profound rightness of the basic conviction in Vedanta ..that sacred, mystic formula which is yet really so simple and so clear; *Tat Tvam asi*, this is you. Or, again, in such words as "I am in the east and in the west, I am below and above, *I am this whole world*'...It is the vision of this truth (of which the individual is seldom conscious in his actions) which underlies all morally valuable activity. It brings a man of nobility not only to risk his life for an end which he recognises or believes to be good, but—in rare cases—to lay it down in full serenity, even when there is no prospect of saving his own person."

To understand the physical world, ever since Galileo and and Newton, mathematics —the most powerful and penetrating expression of human reason—has been the indispensable key. As mathematics advances, so does our understanding of the external world. This is well illustrated by the theory of relativity and quantum mechanics. Newton held that there are two Books of God, one the Holy Bible and the other the *Book of Nature* which is in the language of mathematics.

Mathematics, and experiments, unravel the secrets of the atom. On the other hand, self-control and 'moral experiments' lead to self-knowledge and self-liberation. *Moral experiments have the same place for the internal world, as physical experiments have for the external world.* Without continuing experimentation and assessment, there can be no advancement either of the individual or of society. Recall Gandhiji called his Autobiography as '*The Story of My Experiments with Truth.*' He writes : ("*My Experiments with Truth*) will of course include *experiments* (italics added) with nonviolence, celibacy and other principle of conduct believed to be distinct from truth. But for me, truth is the sovereign principle, which includes numerous other principles. This truth is not only truthfulness in word, but truthfulness in thought also, and not only the relative truth of our conception, but the Absolute Truth; the Eternal Principle, that is God... I am prepared to sacrifice the things dearest to me in pursuit of this. Even if the sacrifice demanded be my very life, I hope I may be prepared to give it... Though this path is straight and narrow and sharp as the razor's edge, for me it has been the quickest and easiest."

And in his ceaseless quest, he heard the 'Voice of God'. I can say this that not the unanimous verdict of the whole world against me could shake me from the belief that what I heard was the true Voice of God... For the voice was more real than my existence."

He concludes his *Story of the Experiments* with the words : "To see the universal and all-pervading Spirit of Truth face to face one must be able to love the mearest of creation as oneself.. I must reduce myself to zero. So long as a man does not of his own free will put himself last among his fellow-creatures, there is no salvation for him. Ahimsa is the farthest limit of humility."

Einstein said‡ (1939) of Gandhi that "generations to come will scarce believe that such a one as this ever in flesh and blood walked upon this earth." Very significant is Einstein' observation : Revolution without the use of violence was the method by which Gandhi brought about the liberation of India It is my belief that the problem of bringing peace to the world on a supranational basis will be solved only by employing Gandhi's method (*Satyagraha*) on a large scale." And how spiritually close are these two unquestionably the greatest of human beings.

When asked (during a serious illness) whether he was at all afraid of death Einstein said, "I feel such a sense of solidarity with all living things that it does not matter to me where the individual begins and ends." And he added "There is nothing in the world which I could not dispense with at a moment's notice." (Born, 1971.)

The *Katha Upanishad* declares : "When every desire that finds lodging in the heart of man, has been loosened from its mooring, then this mortal puts on immortality : even here he tastes God in this human body." (Shri Aurobindo's translation II-3-14) It was about this stanza that Paul Deussen said that no nobler, profounder words had been ever uttered by human lips. It speaks of God realization *here* and *now*.

There is unambiguous testimony for God realization 'here and now' by seekers of highest integrity and spiritual attainments in all ages and countries. The evidence is far too significant to be evaded or ignored.‡‡ It would not be in keeping with the

‡Quotations from Einstein are from A. Einstein, *Ideas and Opinions*, Crown Publ., New York (1954); O. Nathan and H Norden, *Einstein and Peace*, Methuen, 1963; and K. Brecher, *Nature*, 278, 15 March 1979.

‡‡C. G Jung has written much on religious experience. He says [*Psychological Reflections An Anthology of the writings of C G. Jung*, selected and edited by Jolande Jacobi, Pantheon Books (1953)]:

"Religious experience is absolute. It is indisputable. You can only say that you have never had such an experience and your opponent will say, "Sorry, I have." And there your discussion will come to an end. [XLVI, 188 (B, 113)]

No matter what the world thinks about religious experience, the one who has it possesses the great treasure of a thing that has provided him with a source of life, meaning, and beauty and that has given a new splendour to the World and to mankind He has *pistis* and peace. Where is the criterion by which you could say that such a life is not legitimate, that such experience is not valid and that such *pistis* is mere illusion ? Is there, as a matter of fact, any better truth about ultimate things than the one that helps you to live?" [XLVI, 188f(B,113f)]

temper of science to do so. William James (whose writings had no negligible influence on Niels Bőhr has given an illuminating discussion of mystical experience in his Gifford Lectures on *Varieties of Religious Experience*. Sri Ramkrishna speaks of his actually 'seeing' God; of 'talking' to him. ".. God is beyond the power of reasoning.. I do actually *see that whatever is, is God.*"

It is apparent that soul or God cannot be *proved* by reason or logic. Nor can it be *disproved*. This is beyond question. Any logical reasoning must start from some unproved postulates and some undefined terms. Any postulate (axiom) that we may presuppose to prove (or disprove) God would in effect tantamout to our withdrawing from that position. We may take God and Absolute Truth as identical concepts—undefinable, unprovable. Though reason is indispensable for moral quest, the concept of morality rests ultimately not on reason but on faith in God in some form or the other. The distinction between 'right' and 'wrong', between 'good' and 'evil' is not a scientific distinction. It goes beyond science, beyond reason. Anti-reason has no place in beyond-reason. Bertand Russel says in *Wisdom of the West* (1959) :".. We cannot give scientific justification for goals that we might pursue or for the ethical principles that we adopt. We can begin to argue only if we admit, from the outset, some ethical premises... Most of the principles which make for civilized living are of this ethical character. No scientific reason can be given why it is bad to inflict wanton cruelty on one's fellows. To me it seems bad ..(but) I am not sure that I can supply satisfactory reason." In the end, it is the 'small voice' within a *pure* heart that alone can tell what is right and what is wrong.

If 'self', mortality, and God are beyond science, what contribution can science make to self-knowledge and moral behaviour ? The answer is yes; and the contribution is extraordinarily large. It is most far-reaching, and rapidly increasing. We can divide the discussion under a few headings, some what overlapping. It will include the problem of *interaction* between self and atom.

VI. Superstitions about Outer and Inner Worlds

Nothing has done more than science to loosen the hold of magic and superstition on the minds of men. When there is no framework of objective knowledge as provided by science, everything seems possible. For example, a bird sitting on the yonder tree may be what it seems to be or it might be something else under spell of magic. *Science limits the possible*. By continually deepening our understanding of nature, science tells us more and more of what is permissible in nature and what is not. Where can we find a more inspiring account of the impact of science on superstition than in Charles Sherrington's *Man on his Nature*. Writes Sherrington : "(Before Galileo and Harvey) Magic and sorcery were part of the belief not merely of the common folk but of the cultured, especially those of "progressive" view... Cultured liberal opinion was inclined to medical astrology as the climax of scientific

medicine.. (Today) our insight into nature is of a different order from theirs of yesterday...The half-gods are not only vanished, they are by nigh forgotton; matter for labels and a museum-shelf." And he continues : "Today man can go out into the natural world without carrying the distortion of monstrosity with him. We can interrogate the natural world with a confidence drawn ftom riddance of misunderstanding no less than from extension of understanding...The position for reading from Nature's lips what she may have to say of Godhead never yet in the past was what it is for us today." (Chapter II—*Natural and Superstition*).

Science education, in countries where it is widespread, has gradually banished to a large measure magic and superstition about the external world. But there still remains, as strong as ever and possibly stronger, the far more dreadful 'Superstitions' of the inner world : *Greed, Hatred, and Delusion*. These are the roots of all violence and wars. And though there is no war *for* science, yet science-based technology has amplified beyond measure cruelty and destruction of wars. Greed, Hatred and Delusion (GHD) cannot be conquered except by knowledge and self-control. There is no other way, no Royal Road.

Nuclear weapons and uncotrolled GHD cannot coexist. It can only lead to a total collapse of civilization. It is a sad thing, a fault of public education, that enough people are not aware of the global danger facing mankind. The very survival of the human species is at stake, nothing less than that. And the only hope lies in the common people becoming aware of the unprecedented danger that faces them and their children. Remarkably, in the very same century in which men deployed nuclear bombs against fellowmen, the expanding knowledge of the natural world has disclosed an unexpected relatedness and pervading harmony in an amazing diversity. It seems that the emergence of man from the lower primates has probably its roots in cooperative and altruistic behaviour. This brings us to our next point—man and his kinship with all living beings.

VII. Man's Kinship with Living Beings

The recent work of Konrad Lorenz and others has shown that in Nature, harmony is the normal rule and conflict an exception. Members of the same species never kill one another. Their fights are either sport or ritual. There are a few species which deviate from the rule. And the greatest exception is the human species (which calls itself Homo sapiens—man the wise). Homo sapiens torture and murder one another in war and peace, with an abandon, wantonness and brutality that has no parallel in Nature. It is Man's gift to Nature. Within a span of 40 years, two World Wars killed many tens of millions of people. How deep and pervasive are the effects of GHD (Greed, Hatred, and Delusion) ? More than 60 per cent of all world's research and development work in science and technology is directed to military ends; and $400 billion a year is the global military expenditure (300,000-

crores of rupees), and still increasing. Some 700 million human beings are living today in absolute poverty—hungry, illiterate, and disease-ridden. The link between the two is apparent. Total comprehensive disarmament and elimination of global poverty go together.

The food problem of poor countries has been aggravated by large increase in recent decades of consumption of animal protein by people in rich countries. A third of the world's yearly total output of cereals is used as animal feed to produce animal protein. About-5-20 kilo of vegetable protein goes to produce a kilo of animal protein. This is done by industrial animal-breeding methods of unspeakable cruelty. We cannot be cruel to animals and expect that it will not harden human sensibility towards fellow human beings. In the long run, cruelty is indivisible; so is compassion. Alfred Kaestler (of optical pumping fame) at a UNESCO roundtable in June 1978 observed that since animals are our 'biological brothers', the time has come that in the interest of man's own future, "this relationship is legally recognised." The suffering of animals and of man is in the end not separable. No longer the rigid *Cartesian Partition* between human beings and other living creatures is tenable scientifically. We need to get away from it completely. It is totally unreasonable.

VIII. Science and Faith

The pursuit of scienceres ts ultimately on our *faith* that nature is understandable by the human mind. The faith is reinforced by the advancement of science itself. Einstein says : "Certain it is that a conviction, akin to religious feeling of the rationality or intelligibility of the world lies behind all scientific work of a higher order. This firm belief, a belief bound up with deep feeling, in a *Superior mind* (italics added) that reveals itself in the world of experience, represents my conception of God." Ten years later (1929) he wrote : "I cannot conceive of a genuine scientist without that profound faith (—the universe is comprehensible to reason). The situation may be expressed by an image : *Science without religion is lame, religion without science is blind*". This reminds us of Heisenberg's view that science points to some Central Design, some purpose in the Universe (Heisenberg, 1971).

The extraordinary beauty, power, and fertility of Mathematics has a profound influence on a sensitive mind. Mathematical results are communicable. These can be discussed and criticized. This is very different from transcendental or yogic experiences. These are ordinarily not communicable. Perhaps, no path takes us closer to *communicable* Truth than abstract mathematics at its best. Plato declared that none enter his Academy if he had no love for mathematics. Why mathematics provides *the key* to the physical world ? In truth we do not know, cannot-know, the answer. James Jeans said many years ago, 'God is a pure mathematician.' And more recently Dirac (1964) said that "(God) used very advanced mathematics in constructing the

universe,... (and) as, we proceed to develop higher and higer mathematics we can hope to understand the universe better. It may well be that the next advance in physics may come about... (by) people first discovering the equations and then ..the physical ideas behind the equations." This, of course, is an expression of faith, and not logic. In oversimplified terms, we may say that as mathematics is the golden key to *communicable* Truth or Reality, the key to *non-communicable* Truth is mystic experience, that is yoga. The highest yogic state is possible only when *all* desires lodged in the heart have been dissolved. In a state of "I" reduced to zero, "insights" may be permissible which are ordinarily inaccessible, going beyond physical limitations of space-time. These may be partially communicable. There are accounts whose authenticity cannot be doubted. We may assume that the ultimate source of yogic insights and other creative insights is the same, by whatever name we may call it, for the simple reason that both belong to man.

Transcendental experience goes beyond science. But as we have emphasised, beyond-science is, totally different from a contradiction of science. To admit contradiction in a realm which belongs to science is not only a violation of our scientific experience, but much more is at stake. And let us note that the cumulative scientific experience is extraodinarily wide-ranging, and extraordinarily coherent and deep, going to the very heart of Nature – and extending to the farthest limits of the universe in space and time. A violence to science is a violence to our 'cosmic religious feeling,' to our most precious and cherished faith that Nature is understandable.

IX. Physics and Philosophy

Moral and spiritual thought is not a part of Natural Science. Terms like "spiritual energy", "mind energy". or "moral force" are nonsensical, if energy and force are conceived as having a semblance to the terms "energy" and "force" as used in science. A lot of confusion is caused on this account in the popular mind. On the other hand science, especially modern physics, provides suggestive analogies which can help better understanding of moral and spiritual thought. But the analogies should be treated as no more than analogies. Take the famous *Santi-Sloka* of the *Isavasyopanishad*. It says that the Supreme Whole (Isvara) is such that it remains Whole even if Whole is taken out of it, or Whole is added. It reminds us of the concept of the *mathematical infinity*, developed for the first time in the 19th century. An illustration from physics is of the velocity of light. A fundamental postulate of the theory of relativity is that whatever velocity we add to or subtract from, the light velocity, it remains unchanged.

As the language of science becomes richer with advancement of science, it enriches possibilities for better appreciation of deep metaphysical concepts such as self, Soul or God, concepts that inevitable involve contradictions. For an analogy from

mathematics, recall Göedel's celebrated theorem on the "incompleteness" of mathematics. He *proved* that in mathematics, the most precise part of science, there is no escape from concepts with latent contradictions. The contradictions are latent in the infinity of integers which are the foundations of mathematics. This most astonishing discovery has both for science and philosphy consequences of the greatest significance, not yet clear.@

Concepts like *Self, Time, God* are embedded in the deepest core of our language. Take these away and language collapses utterly.

A word about Time. The mysterious and self-contradictory nature of Time is apparent on a little reflection. On the one hand, ***Past*** and ***Future*** extend to infinity, and, on the other hand, these are contained in the single moment *Now*, for otherwise these would not exist at all. Göedel (1949) is of the view that Einstein's relativity theory by its deep and surprising insight into the nature of *phyisical time* provides "an unqualified proof for the view of those philosophers who, like Parmenides, Kant, and the modern idealists, deny the objectivity of change and consider change as an illusion or an appearance due to our special mode of perception."

Another major development in modern physics with far-reaching philosophical and ethical implications is Böhr's *Principle of Complementarity*. No longer can we keep physics and philosophy, or atom and self, apart. Max Born goes so far as to say that theoretical physics today is actual philosophy. Recall Schröedinger's statement on the aim of science. As we probe more deeply into the nature of the atom and the universe, it is becoming increasingly clear that physics and philosophy have much to learn from each other.

In the present century, physics has undergone its greatest revolution since Galileo and Newton. The theory of relativity paved the way for de Broglie waves and quantum mechanics. In the preface to his great book, *The Principles of Quantum Mechanics*, Dirac writes : "The new theories, if one looks apart from their mathematical setting, are built up from physical concepts which cannot be explained in terms of things previously known to the student, which cannot even be explained adequately in words at all. Like the fundamental concepts (e.g., proximity, identity) which everyone must learn on his arrival into the world, the newer concepts of physics can be mastered only by long familiarity with their properties and uses."

@Goedel's work has established that any logical system, which at least includes ordinary arithmetic, necessarily contains statements that can be neither proved nor disproved within the system, but which are nonetheless intuitively true—that is, there are statements that are 'obviously' true but are not provable. ***Thus, even in mathematics we must admit truths that are not provable*** That there is no escape from this has been conclusively demonstrated by Göedel. He also proved that the ***axioms*** of any logical system which depends on ordinary arithmetic cannot be guaranteed to be consistent, that is, free from hidden contradictions

The philosophy of modern physics has a special relation to Upanishadic and Buddhistic thought. Ernst Mach's critical analysis which brought to light deep flaws in Newtonian mechanics exercised a profound influence on the young Einstein. Mach, as he himself acknowledged, was deeply influenced by Indian philosophic thought. *This important aspect of the history of modern physics is still largely an unexplored chapter* (Kothari, 1979).

The starting point of relativity theory is a completely unbiassed examination of the nature of time and space in physics, free of all pre-conceived notions no matter how deeply rooted in common sense or philosophy. It demands a renunciation of the concept of absolute time which was the foundation of Newton's dynamics. The constancy of the velocity of light, independent of the state of motion of the observer, requires inevitably that there is no *absolute time*, that is, there is no common time for all systems. @@ On the other hand, every physical system has a *time* of its own which depends on the state of motion of the system. Suppose the velocity of a system, in motion with respect to us, approaches the velocity of light. All physical and biological processes occurring in the system, as *observed by us*, will be slowed down more and more. There will come to a *dead stop*, if the velocity of the system were exactly that of light. There is no flow of time for a system moving with the speed of light. For such a system there is no ageing whatever, that is, there is immortality'. A direct consequence of Einstein's theory is the following. Suppose a person travelled with nearly the speed of light to a near star and returned to earth without stopping on the star. For *him* the time elapsed would be no more than a few seconds or so. But here on earth, he would find everything older by many years. This is tantalisingly paradoxical for common sense, but so much the worse for common sense. We must accept as inescapable the reality of the relativity of time and the unreality of absolute time It is required by fundamental physical theory and unambiguous experimental evidence.

Speaking about time in physics, there are as it were a *hierarchy of time*, 'levels of time', in the words of Prigogine (1974, 1978) who has made far-reaching contri-

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@The concept of ***absolute space*** implies the idea of ***absolute rest*** and ***absolute velocity***. Galileo showed that the idea is meaningless. With the concept of an all-pervading luminiferous ether in the nineteenth century, there was a return to the concept of absolute space. ***Absolute time***—the time which characterizes Newton's equations of motion—is founded on the idea that ***absolute simultaneity*** of events at different places has a precise, well-defined meaning. Einstein showed this to be mistaken. Both ***absolute space and absolute time*** were demolished by Einstein's theory of relativity. Time and space were reduced from the status of ***nonmena*** to ***phenomena***, that is, 'appearances' dependent on the state of motion of the observers. Interestingly, the ether is again re-appearing in a totally new form, ***the quantum ether***, a result of an interaction between general relativity and quantum theory. [See Bryce S. Dewitt, ***Quantum Gravity: the new Synthesis*** in ***General Relativity. An Einstein Century Survey***, edited by S.W. Hawking and W. Israel, Cambridge University Press (1979)]

bution to the problem. For a purely dynamic system, an atom, for example, there is no distinction between past and future. This means that from 'the behaviour of a purely dynamic system, we cannot determine the arrow of time. This holds both in classical and quantum mechanics. But for a thermodynamic system, on the other hand, time is not reversible. A hot body left in the open always gets cooler with time till its temperature is that of the surroundings. Past and future are not interchangeable for thermodynamic systems. Thermodynamic systems are large systems. A large system is one which consists of a large number of small systems. What is a *small system*, we discuss later.

The next level of time is time associated with evolution or history. This applies to non-linear thermodynamic systems far removed from thermodynamic equilibrium. Prigogine's work has brought out a suggestive complementarity between dynamics and thermodynamics, in the sense of the wave particle complementarity.

We may also mention the *two* times of Dirac, the *atomic time* and the *cosmological time*. The concept of *two* time leads to a continuous creation of matter.+ At the highest level of time, we may think of an "absolute time of the universe." When the object of investigation is the whole universe, there is no other physical system to which it could be related. There arises no question of relativity of time, and we have an *absolute* cosmological time.

We have been speaking so far of the physical time or clock time. This is time for physical systems, not time for a *'self'*. The psychological time, *the time as experienced by a self*, has little *direct* relation to physical time. What may be no more than a few seconds of physical time, the time as experienced by a self—call it psychological time—could be very large. In certain critical situations it could be near eternity, but we do not know.

What about the concept of beyond-time? It is envisaged, for example, in the *Sankhya Darshan.* Kant recognised such a possibility. He says: "Those affections which we represent to ourselves as changes, in beings with other forms of cognition, would give rise to perception in which the idea of time, and therefore also of change, would not occur at all."

To ask the question *what is truth?* (whether about atom or self) is to raise the problem of time. For truth, if the concept means anything at all, implies continuity, survival in time. A *partial truth* must contain some grain of everlasting truth. As we learn more about 'levels of time' there will emerge a more unifying vision of Nature.

+Dirac has presently modified his theory of *two* times so as to incorporate conservation of matter in the visible universe [*Proc. R. Soc*, 365, (A), (1979) 19-30]

X. The Principle of Complementarity

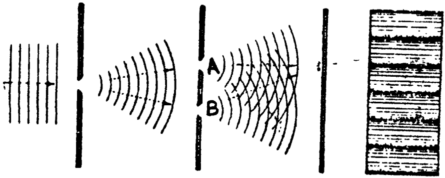
Einstein wrote in 1951 : "All these 50 years of conscious brooding have brought me no nearer to the answer to the great question. "What are light quanta?" Now a days every Tom, Dick, and Harry thinks he knows it, but he is mistaken." (Banesh Hoffmann, 1973).

Light quanta, electrons, and atoms, are small objects. An orange is a large object But in comparison to the earth an orange is very small; as small as an atom is compared to an orange. *What the new physics does is to give an absolute meaning to the concept of 'small' and 'big' objects.* An object is *small* in the absolute sense if the effect of the *'disturbance'* which inevitably accompanies an act of observation is not negligible. A certain indeterminate disturbance is inevitable even under *ideal* conditions, that is, observations made with 'perfect' instrument' supposed free of all limitations except what are inherent in the very nature of things. If the disturbance has a negligible effect on the state of the object, the object is said to be *big* in the absolute sense. The moon is a big object, because looking at it, observing its motion has no effect on the motion of the moon. An electron, or an atom, is a *small* object in the absolute sense, because the unavoidable disturbance (inherent in an act of observation) drastically alters the state under observation. Note that a perfect observation, in an imaginary observation with ideally, 'perfect' instruments. It is a kind of 'thought experiment' : the only requirement for it is that it should be theoretically permissible. It should conform to the laws of physics. *Ideal experiments are useful tools of thought.* A certain indeterminate disturbance accompanying an observation, totally unpredictable, is inherent in the very nature of things. Nature is made that way. It is a direct consequence of the existence of the Planck's constant. To *appreciate the absolute distinction between big and small system is the gateway to modern physics.* (Where such an absolute distinction is not called for, we shall continue to use the words big and small in their everyday sense).

Permit me to present a brief description of something so well known. Think of a beam of photons (light quanta) starting from a light source and falling on a distant target, say a photographic plate. On the way, before reaching the target, the particles pass through two or more narrow slits in a screen. On the photographic plate a certain pattern of fringes is observed. These interference fringes can only be explained on the basis that each photon passes undivided through all the slits at the same time. This is an imperative requirement. It seems impossible ! How can a photon pass through a number of slits at once? But there is still more to it *(see Figure on p. 20).*

A similar experiment with a beam of electrons, requiring great sophistication, was first made a little over 50 years ago. The light experiment is nearly two hundred years old. The electron beam forms an interference pattern on the plate, essentially

no different from what is obtained for a beam of light. The interference pattern can be accounted only on the assumption that each electron goes through all the slits in the screen it meets on its way to the photographic plate It is not as if some electrons go through one slit, some through another, and so on. No, not at all. *Every electron goes through all the slits* ..The situation is altogether unimaginable, inconceivable. How can an electron, the same electron, cross through a number of slits at the same time ? Impossible ! How can the same electron be at two different places at the same



A beam of particles travels from left to right, and forms a pattern of interference fringes on the plate at extreme right To explain the ***observed*** interference pattern it is imperative that ***each*** particle passes, at the same time, through both the holes (A. B.) in middle plate. This sounds impossible—Crazy beyond words, and so it is : ***see text***

time? You and I cannot pass through two doors at the same time; and yet the photons and electrons do that as if it were a normal thing for them. What is the reason ? It is none other than the fact that photons, electrons, atoms, are *small* objects – small in the absolute sense; and you and I are big objects in the absolute sense. The small objects, judged by the behaviour of big ones, perform literally miracles (*see* Heisenberg, 1958, pp. 157–160).

Consider an electron on its way from its source to the target plate. Quantum mechanics tells us that the (unobserved) electron is not moving as a 'particle'. A particle could not pass through two or more holes at the same time. The electron is moving in the form or guise of a 'wave' – a wave of *probability amplitude*. These waves are not in physical space, not in our everyday space, but in an abstract mathematical space that can have many dimensions. [If the electron wave were in physical space, we could see it—but we don't. A photon, or an electron, has a *dual* aspect, a wave aspect and a particle aspect]. The two aspects are complementary. The one aspect excludes the other aspect. That is why the two aspects are not contradictory. A contradiction between them could arise only if the two aspects could be observed at the same time. But this never happens; and we have compelling theoretical arguments that this could not happen. *The wave and the particle aspects are complementary and not contradictory.*

New developments in quantum mechanics and gravitation, leading to a possible unification of the two, are likely to bring to light 'higher levels' of complementarity, not yet envisaged.

Speaking of the wave-particle duality of the electron, it is interesting to note that whereas *thermal* ionization brings out the *particle* aspect of the free electron gas (*non-degenerate gas*), *pressure* ionization brings out the wave aspect (*degenerate gas*). *Thermal* ionization and *pressure* ionization are complementary. The theory of presure ionization requires that the large planets consist mostly of metallic hydrogen; and that there cannot be a 'cold body' bigger in size than Jupiter. It appears probable that *metallic hydrogen* has been recently produced under pressures of a few million atmospheres. (*Science*, 4 August 1978). It could be superconducting even at room temperatures, but we do not know.

Theoretical physics enables us to calculate the wave functions for simple atomic systems. In principle, these can be constructed for any system, whether small or big. For a big system this is unnecessary because we can use for it the much more familiar Newtonian mechanics. Wave functions give the *probabilities* of every possible results obtainable on observation of the system under consideration. It is inherently impossible to predict with certainty what a particular result is going to be in the case of a particular observation. This is because of the inevitable, uncontrollable indeterminate disturbance inherent in an act of observation. When an electron, or as a matter of that any small system, is not under observation, its course of development, that is, the change in its state of motion, cannot be conceived in our everyday space. It takes place in an abstract mathematical space. An act of observation throws the system into our ordinary space, the manifest space. This all looks so bizzare. Ordinary language—but not mathematics—fails to describe the situation without introducing absurdities. This is understandable for ordinary language has not evolved to deal with *small* objects. It is based on our everyday experience with large objects. Expressed in ordinary language, the behaviour of small objects is desperately anti-commonsense, exasperating. The world of small objects, small in the absolute sense, is built that way. *Large objects behave according to commonsense but not small ones.*

We shall not go here into the famous Einstein-Böhr controversy about the probabilistic foundations of quantum physics. The famous Einstein-Podolsky-Rosen paper of 1935 on the 'incompleteness, of quantum mechanics was answered by Böhr; but not to Einstein's satisfaction++. The debate led to many interesting developments

++Einstein writing to Schröedinger (9 August 1939) says that he is as convinced as ever that quantum mechanics does not give a complete description of reality "The mystic (meaning Bohr)... forbids, as being unscientific, an inquiry about something that exists independently of whether or not it is observed, i.e., the question as to whether or not the cat (reference is to Schröedinger's cat paradox') is alive at a particular instant before an observation is made" (Bannesh Hoffmann, *Albert Einstein, Creator and Rebel* (1973))

(Max Jammer, 1974) in suggesting experiments on the role of 'hidden variables' in quantum theory.

Einstein could not reconcile himself to this probabilistic world of atoms[++]. It was repugnant to his intuition, to his cosmic religious feeling. Gott würfelt nicht," Einstein often used to say in various forms. This may be naively rendered as 'God does not play dice.'

Fundamental discoveries which go deep into the nature of things are the result of uncommon intuition and faith, not cold logic. And what we witness here is a difference in faith, a difference in the cosmic religious feeling, of Einstein and Bŏhr. It reminds us of the difference in the faith of Newton and Leibnitz. In a sense, Einstein's philosophy emphasises 'Being', and Bŏhr's emphasises 'Becoming'.

We go back to the distinction between small objects and large objects. Any experimental set-up for small objects must necessarily consist of large objects, otherwise the set-up will not be unambiguously describable. It will, therefore be not repeatable. If not repeatable, it is not an experiment.

To fix our ideas, think of a large number of identical experiments to determine the velocity of an electron, which at the start of the experiment, let us suppose, is located at some specific point, say, the zero point of the scale. The results of the velocity measurement in these identical experiments will be widely different. This is because of the uncertain disturbance in the motion of the electron caused by the act of locating it, at the zero of the scale, at the start of each of the identical experiments.

If we desire to measure not the velocity but the position of an electron, the experimental set-up required for the purpose will be totally different. But this is not so far a large object. The different experimental set-up required for the measurement of different variables can, in principle, be joined together into one comprehensive apparatus. This one apparatus will measure everything measurable in principle for a big object. There is no objection to this procedure, because observations do not disturb the state of a big object under observation : All possible measurements can be made without interfering with each other with the aid of a single super-instrument. But this is impossible for a small object. Why? The measurement of one variable for a *small* system, because of the non-negligible accompanying disturbance, disturbs the values of the other variables to be subsequently measured. We must, therefore, make a definite choice as to what variable we desire to measure for the system. For example : The set up required for a measurement of position of an electron and that required for a measurement of velocity cannot, in no circumstances, be combined into a single super-instrument. [This is the essence of Bŏhr's argument for rejecting the EPR thesis].

An all comprehensive instrument is impossible in quantum mechanics; because, in general, *measurements are not compatible with one another for small objects.* It is important to grasp this radically new situation.

At the root of the wave-particle duality *is the principle of absolute indistinguishability, absolute identity of particles of the same kind.* All electrons in the universe are absolutely identical, absolutely indistinguishable from one another. What does it mean?

Think of two *identical* particles. If these are to be *absolutely identical,* it should not be permissible to precisely define their trajectories, for otherwise their separate trajectories could be used to distinguish the one particle from the other for all time. One particle riding one trajectory and the other a different one would be distinguishable by their different trajectories. Absolute identity of particles demands that there cannot exist for them *sharply* defined trajectories. This leads to the wave aspect; and hence the waveparticle duality, and with it the Heisenberg uncertainty relations. The periodic table of elements, and nearly all chemistry and bio-chemistry is a direct product of the *absolute identity of electrons.* How ? The identity principle introduces a fundamental and exceedingly simple symmetry in the wave functions of electrons. In response to this symmetry, chemical compounds are formed.

Think of the total wave function of all the electrons in a piece of metal. We may in principle do the same for all the electrons in the Universe. In this total wave function, the identity of the individual electrons is completely, absolutely lost. Not a trace of their separate individuality is left. One electron has absolutely the same role in the total wave function as any other electron. *The electrons have submerged themselves, as it were in one 'brtoherhood' of electrons.* The Many have become *ONE.* Note that as stated earlier, the wave function exists in an abstract mathematical space, not in physical space. The individual electrons can be observed, if we so choose, but then the act of observation would project the electrons from the mathematical space into our everyday space. The observation would drastically alter the state which was there before the observation.

When we speak of the total-wave-function or the field, and the many identical particles incorporated in the wave function, it is not a sort of an aggregate, a sum of the MANY. In an aggregate, the ONENESS is no more than an euphemism for the MANY that are still visible, may be dimly, in the aggregate. The concept of ONENESS in quantum mechanics is a totally, fundamentally, new concept. It has no analogy, no parallel, whatsoever in classical physics or in everyday experience. Common sense fails utterly to be of any aid. *The ONE is in an abstract space, the MANY in physical space.* The two aspects are complementary. All this is a consequence of Planck's constant. *We may say that Nature (or God) created the Planck Constant so that particles of the same kind in the Universe could be absolutely identical.*

There is an interesting analogy between the behaviour of an atom and the self as regards disturbance caused by an act of observation. The state of an atom is disturbed if it is observed. In psychological investigations of a conscious subject, or during introspection, the act of investigation disturbs the mental state under investigation. Suppose one wants to find out how he actually goes to sleep. So long as he is alert (awake, so that he can find out how sleep comes to him), the very fact of alertness prevents him from going to sleep. We can never know how we *actually* go to sleep. That is impossible in the very nature of things.

XI. Role of Consciousness in Quantum Mechanics

We spoke of the *absolute* indistinguishability of particles of the same kind e.g. electrons, in quantum mechanics. We have a most remarkable, thought-provoking analogy drawn from modern physics for the great *Upanishadic formula* : the different individual selves on the empirical plane are ONE and the Same on the transcendental plane : *Tat tvam asi.* Perhaps, there is a little more here than mere analogy. For, it is important to recognise that in *quantum mechanics, consciousness or self, has a significance which has no counterpart in classical physics.* This was emphasised by von Neumann, and further developed by many others notably Wigner. We have seen that an act of measurement, even an ideal one, inevitably and upredictably disturbs the state of the dynamic system under observation. But what precisely is a measurement: and when can it be said to be completed ? It would take us too far to discuss this question at all adequately. Even after, more than 50 years of quantum mechanics there is no unanimity of views on this point. It is still a "live issue'. We may state the following considerations, partly overlapping, which are relevant to the role of consciousness in quantum physics.

(*a*) An act of measurement in quantum mechanics requires a *choice* between incompatible experimental arrangements. An act of choice implies a conscious subject or self to do the choosing. *A choice is neither determinism nor is it chance.* It implies a certain freedom to elect between possible alternatives. Consciousness and freedom of choice, or free-will, go together. This is crucially important. A computer has no choice of its own : the choice belongs to its programmer. That is the fundamental distinction between a computer and its programmer.

(*b*) An act of measurement is not completed until the result of the measurement has been noticed by some subject, noticed by some self. In the oft quoted words of E.P. Wigner (1964) : "The measurement is not completed until its result enters our consciousness...(this) last step is, at the present state of our knowledge, shrouded in mystery and no explanation has been given for it so far in terms of quantum mechanics, or in terms of any other theory." On the other hand, it has been argued by others that a measurement is effectively completed, if the result is recorded in some instrument. An 'entry into consciousness' is not necessary. What

is necessary is an irreversible thermodynamic change resulting from the measurement process. (This is the answer to the 'cat paradox' of Schröedinger). We shall not go further into this subtle question. It is enough to note that the very concept of a measurement process in quantum mechanics demands an irrevocable choice between incompatible set-ups. And choice demands a conscious subject to exercise the freedom of choice.

(c) Suppose for a moment that electrons possess some kind of self-awareness. This, as we shall see in a moment, leads to a *reductio ad absurdam*. It is obvious that if the electrons have their own *separate egoes*, they cannot be absolutely identical. Under these circumstances, there can be no wave-particle duality Therefore, to be consistent with modern physics, we require that *self-awareness cannot arise in small systems*. It is interesting that such a significant conclusion follows directly from quantum mechanics. Self-awareness can appear only in a large system. As self-awareness carries with it an 'arrow of time', the large system must be a thermodynamic system far removed from thermodynamic equilibrium.

Notice that the property of self-consciousness relevant to quantum mechanics is its freedom of choice, or free-will. And it is this property, and this alone, which unambiguously distinguishes consciousness from matter, or self from atom. For matter there is necessity and chance, but no choice or freedom and freedom is the basis of all moral activity.

I feel within myself—and we all do the same—absolutely certain that I am free to write this sentence or not write it. But what does it all mean? How can my consciousness or mind exercise its choice of writing or not writing this sentence, except by interacting with my body, that is, by interacting with matter? Everything we do, everything without exception, is a direct expression of brain-mind interaction. Yet science provides not the faintest clue as to how such an interaction could occur. It is totally beyond explanation, totally beyond understanding. It is the supreme mystery; for it is an interaction between one element (brain), which is within space-time and another element (mind or self) which is *outside* space-time.

Despite the earlier, rather lengthy, discussion we may still feel uneasy to admit a reality other than matter, a reality outside the framework of space-time and matter-energy concepts. How can we physicists admit any *reality* outside physics? It may appear more satisfying, more comforting, to hold that matter or atoms, are everything. That besides matter there is nothing: and that sooner or later every thing would be accounted for in terms of atoms and sub-atomic entities. But, pray, *who* is this entity about whose satisfaction and comfort we are so much worried? *Why not ignore this who?* Has this *who* any reality or is it only an 'appearance', not worth bothering about? We are now back at the beginning: *who are we?* Science cannot, and must not, evade its task and its responsibility. Developments in physics

in the present century have clearly brought out the need and urgency in this respect. And, of course, science cannot contribute meaningfully to the great moral challenge facing mankind today, the greatest in man's history, unless it recognises its obligation to the problem of the 'self', and not merely that of the atom.

At this point, there may arise the doubt that if the *objectivity* of science excludes totally the 'I' from it, how could science tell us anything at all about the 'I', and the nature of the self? The answer is : It can. How ?

Firstly—that developments in mathematics and physics in the present century have demonstrated convincingly that science is, by its very nature, 'incomplete'. There can be 'reality' not encompassed by science. The 'incompleteness' is not in the ordinary, expected sense that there will be always far more to discover than discovered so far : science is an 'endless quest'. We are not here speaking of 'incompleteness' in this obvious sense. But in the extraordinary and totally unexpected sense that there are fundamental truths, about which we are intuitionally certain, but which must always remain outside the domain of science. (Recall Goedel's theorem). As the work of Tarski and others has shown, the concept of *truth* is itself a telling example of this. To quote M. Delbrick (Nobel Address, Dec. 1969). "Thus, even if we learn to speak about consciousness as an emergent property of nerve nets, even if we learn to understand the processes that lead to abstraction, reasoning, and language, still any such development presupposes a notion of truth that is prior to all these efforts and that cannot be conceived as an emergent property of it, an emergent property of a biological evolution. Our conviction of the truth of the sentence, "The number of prime numbers is infinite," must be independent of nerve nets and of evolution, if truth is to be a meaningful word at all."

This reminds us of Einstein's remarks on Scientific Truth and his conception of God. He said (1929) : "This firm belief (in the intelligibility of the world), a belief bound up with deep religious feeling, in a superior mind that reveals itself in the world of experience, represents my conception of God. In common parlance this may be described as 'pantheistic' (spinoza)."

Secondly—Science, especially psychology and the neuronal sciences, can be used to explore the *objective aspects* of the mind and self—whatever these may be.

Thirdly—as our knowlede of mathematics, physics, and the neuronal networks increases so also, by exclusion and comparison, our understanding of the self gets richer. On the analogy that consciousness enters into quantum mechanics, a deeper study of yoga and mystic experience may reveal some reciprocal aspect : we do not know.

Fourthly—the specific, and formidable problem of brain-mind interaction. This needs investigation from brain to mind, and mind to brain, with increasing use of sophisticated techniques and refinements.

Fifthly—the foundations of quantum mechanics need deep and critical examination. As the brain is subject to the laws of physics, the freedom exercised by the mind in brain-mind interaction can take place only within the confines permitted by the indeterminacy which is an integral feature of quantum mechanics. *For the operation of free will, quantum indeterminacy is necessary but not sufficient.*

There is also need for a better understanding of the concept of probability. This may require radical developments in mathematics.

We may note in passing that the role of individual consciousness in quantum mechanics has a certain obvious analogy to the role of Cosmic Consciousness in relation to the Universe; but we shall not go into it here.

Sixthly—Scientific study of what Jung calls the phenomena of *Synchronicity*, that is meaningful 'coincidences' of events. Such phenomena are inexplicable not merely because the cause is unknown, but for them, the "cause is not even thinkable in intellectual terms." The course of our lives is paved with such meaningful coincidences.

The book, *The Interpretation of Nature and the Psyche* (Routledge and Kegan Paul, London, 1955), contains two essays, one by C.G. Jung (*Synchronicity, a causal Connecting Principle*) and the other by W. Pauli (*The Influence of Archetypal Ideas on the Scientific Theories of Kepler*). Jung says that the synchronicity principle advanced by him throws light on the body-soul problem. He says : (p. 124) "*The absolute knowledge* which is characteristic of synchronistic phenomena, a knowledge not mediated by the sense organs, supports the hypothesis of a self-subsistent meaning, or even expresses its existence. Such a form of existence can only be transcendental. since, as the knowledge of future spatially distant events shows, it is contained in an irrepresentable space-time continuum."

It has been noticed for quite some time that there are certain remarkable 'coincidences' among the physical constants. It seems that were it not for these apparent 'coincidences', there would be no life, no man, on the earth : in fact, there would be no earth. (B.J. Carr and M.J. Reec, *Nature*, 12 April 1979).

Why these coincidences ? Is it a case of some kind of cosmic "Synchronicity", or lack of physical knowledge, or both ? We do not know.

Seventhly—Psychosomatic medicine is directly related to mind-brain interaction. As a challenging speculation it could be argued, in the light of the dual reality of mind and brain, that *whatever is possible physiologically is also possible, within obvious limits, psychologically*. With the growing appreciation of the *two* realities, the role of psychosomatic health care and psychosomatic medicine is likely to be increasingly important in the future.

Eighthly—Study of the 'thought process', and 'thought noise'. *Thought noise* may be defined as random, uncontrolled, distracting thoughts, pleasant and unpleasant that come to us from nowhere, as it were : from the sub-conscious mind, as we say. The degree to which thought noise can be reduced by meditation practices (yoga) could be explored—to a certain extent quantitatively.

Conscious thoughts to a large extent are *determinate*, that is, determined by past thoughts, memory, and so on. This reminds us of something like an 'equation of motion' for a dynamic system. The question arises as to what extent thoughts are *free* and under control of the individual self, and to what extent these are not free Here, analogies and models from quantum physics could be helpful in suggesting interesting lines of new investigation, theoretical and experimental. There is also the question of the relation between thought noise and *creativity*.

The question also arises : on what basis, according to what principle or "frame work", does my or your mind exercise its freedom of will and action ?+++ What guides it ? If freedom of action is entirely uncontrolled, unguided, then the choice made by the mind between possible alternative courses of action is all a matter of pure chance. It will be an entirely random choice, and that is no freedom; and no moral responsibility can be assigned to such random operations of the will. ⊕ On the other hand, if the mind is guided in its choice, how does this come about ? Who guides it ? And if there is guidance, the mind is no longer free in its choice between alternative actions. May be, the freedom is there to enable the individual to link himself with the great "Central Design of the Universe" : to realize ultimately the *Kaivalya* state of being. The freedom of the mind which is *real* at the human level is perhaps an illusion at the metaphysical level. [We may suppose that an individual mind is always in 'contact' with the Supreme Mind; and this is especially close during creative experience.]

Ninethly—The 'fact' of the exclusion of 'I' from the realm of science needs to be constantly reviewed critically in the light of new developments in science and philosophy. It is important to examine how compelling are the arguments, derived from the 'incompleteness' of mathematics and fundamental physics, which requires the

+++ This question is generally ignored. An exception is Schroedinger's discussion of the problem (for, see the Epilogue to his *What is life ?)*.

⊕ In *The Human Mystery* (1979) J.C. Eccles says : "The ***self-conscious mind*** is a ***self subsistent entity*** that is actively engaged in reading out from the multifarious activities of the neuronal machinery of the cerebral cortex according to its attention and interest, and it integrates this selection to give the unity of conscious experience from moment to moment. It also acts back in a slective manner on the neuronal machinery. Thus it is proposed, that the self-conscious mind exercises a superior interpretative and controlling role upon the neuronal events by virtue of a two-away interaction between World I and World II that is the External World the [Internal World]......"

existence of a *reality outside science*. The role of consciousness in quantum mechanics discussed above is one such example. Another inspiring example is the Epilogue on *Determinism and Free Will* by Schröedinger to this book '*What is life*' ?

XII. Conclusion

As I conclude the Lecture, I realise how feeble, jumbled up, and how manifestly superficial has been my attempt to describe the relation between Atom and Self. The simple truth is that we can hardly comprehend the value, harmony, and grandeur of the one without knowing something of the other. One thing, reinforced by recent developments in science, is clear. At the human level, *both* Atom and Self, are equally real equally true. It is the *Sanyoga* of the two which is the human mystery. If the atoms were to declare that we are everything, the only reality, this assertion itself would be meaningless unless there is a Self to believe in it. This is what the *Sankhya* philosophy described long ago. That is what Democritus said. Once the fundamental need for the *two* realities, the external world end the internal world, is grasped, it is but a small step to the concepts of Cosmic Consciousness [See, for example, Schröedinger *Mind and Matter* (1958)].

We have seen that as far as present knowledge goes, and in keeping with the spirit of quantum mechanics, the mind (self) cannot interact directly with matter. Again the mind for its adequate manifestation needs a large, extraordinarily complex apparatus, namely, the human brain. Notice that my mind or your mind cannot directly influence, not at all as far as we know, the motion of a single electron or an atom, which is outside a living brain. But for atoms constituting a living brain, bound to a brain, nothing is more common than mind-brain interaction. That I speak to you and you understand me, are—both of these things—a direct demonstration of the mind-brain interaction. The mind-brain *Sanyoga* is the greatest of all mysteries.

What is mind, or rather, what is self-conscious mind ? It is not easy to define. To define 'mind', we have to employ the mind. Mind becomes both an *object* and a *subject*, and a precise definition therefore is inherently impossible. If you use the entire mental apparatus to define mind, then there is hardly left anything of what is to be defined. On the other hand, if you make nearly the entire mind as the *object* to be defined, then there is little mental resource available to provide the thinking required to do the defining. The situation reminds us of the complementarity we have discussed before. But let us leave out a precise definition of mind. What is really important is the recognition that *mind is an entity*, a *reality*, *apart from matter*. If mind is separate from matter, then there could be, and even need to be, different paths, not totally exclusive, leaning to them : namely science in one case and meditation or yoga in the other. Once we recognise the separate reality of mind, the concept of "Supreme Mind", or "One Mind", is a sense, a natural extension.

Mind is not a thing. In the sense in which we speak of mind, it stands for thought, consciousness, perception, memories, reasoning, feelings, emotions, willing, and so on. Mind stands for 'self', for soul. Its most significant characteristic is unambiguous feeling of freedom to elect between alternative courses of action. At the human level, this feeling is undeniable, it is incontrovertible.

Equally, we recognise, as the greatest lesson of science, that the behaviour of matter is, in all its aspects, fully explicable on an objective basis. To understand matter needs no direct reference to mind or self, or any supernatural agency. *In the realm of natural science, reason is supreme.* Therein lies its extraordinary strength. We believe this will hold for, and will be reinforced by, future advancement in our understanding of the natural world.

As far as our experience goes, mind always occurs in association with matter, the brain. It is, therefore, apparent that the freedom exercised by the mind, and the influence of the mind on the course of physical and biological events, must operate *without* violating the laws of nature. In other words, we believe that the physical laws, as explored by the mind, must involve a certain inherent *indeterminancy*. It is within the limits of this indeterminancy that the mind could exercise its freedom of *interaction* with matter. Quantum indeterminancy is a case in point, though how far it is indeed relevant for the mind-body problem is a matter for future investigation. As the brain is a large system, the role of quantum indeterminancy, it would seem, cannot be anything more than negligible. But against this, we have to remember that the mind-brain interaction is likely to be extremely *non-linear*, and as such the effects could be noticeable even though triggered within the limitations of quantum indeterminancy. Also, it should be remembered that though the brain is a large system, the 'thoughts' are discreet, and (as discussed earlier) furthermore the transition from one thought to another in a sequence of thought is sudden, and the transition process is unanalysable. This is not quite the characteristic of a large system. It seems that when we approach from the side of the mind, the brain does not appear to have the characteristics of a 'large system'. This we should expect, and it is at the root of the mind-brain mystery. The indeterminancy we have spoken of with reference to the mind-brain interaction, permits influence of one mind on another without the mediation of other brains. It also allows for possible influence of the Cosmic Mind on 'individual minds.

It seems certain that with a deeper understanding of *space-time*, the mind-brain interaction mystery is likely to become richer, and open new possibilities for human experience, both in relation to the external world and the internal world.

Be that as it may, it is beyond question that for human advancement we need to pay attention to *both* the knowledge of the atom and the knowledge of the self.

The universal knowledge of the atom has placed in man's hands, for the first time in man's history, *means*, which if *wisely* used, can bring prosperity for all. Otherwise, the very survival of mankind is at stake.

It is a challenge for our education. What the Buddha proclaimed about the imperative need to *know* the mind, to *shape* the mind, and to *liberate* the mind has been never more true than in the Age of Atom

"Truth and Love—Ahimsa—is the only thing that counts", said Mahatma Gandhi. It binds men together, and it binds Man and the Cosmos.

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SCIENCE & AHIMSA*

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In stirring words, Nehru said in his 1959 Maulana Azad Memorial Lecture—*India and the World* : "Can we combine the progress of science and technology with this progress of the mind and spirit also ? We cannot be untrue to science because that represents the basic fact of life today. Still less can we be untrue to those essential principles for which India has stood in the past throughout the ages. Let us then pursue our path to industrial progress with all our strength and vigour and, at the same time, remember that material riches without toleration and compassion and wisdom may well turn to dust and ashes".

The Atomic Age and the "Indian Way"

In the Atomic Age without Ahimsa, that is, compassion and wisdom, there can be no survival for mankind. In his foreword to Swami Ghanananda's book, *Shri Ramakrishna and His Unique Message* (1970), Arnold Toynbee says : "At this supremely dangerous moment in human history, the only way of salvation for mankind is an Indian way. In the Atomic Age, the whole of human race has a utilitarian motive for following this Indian way. No such motive could be stronger, or more respectable in itself. The survival of the human race is at stake. Yet even the strongest and the most respectable utilitarian motive is only a secondary reason for taking Ramakrishna's and Gandhi's and Ashoka's teaching to heart and acting on it. The primary reason is that this teaching is right—and is right because it flows from a true vision of spiritual reality.

In March, 1951, Einstein stated [*Einstein on Peace*, by O. Nathan and H. Norden p. 584 (1960)] : "Revolution without the use of violence was the method by which Gandhi brought liberation of India. It is my firm belief that the problem of bringing peace to the world on a supernational basis will be solved only by employing Gandhi's method on a large scale".

Gandhi, the greatest political genius of our time, indicated the path to be taken. He gave proof of what sacrifice man is capable of once he has discoverd the right

* From Siremal Bapna Memorial Lecture.

path. His work on behalf of India's liberation is the living testimony to the fact that man's will, sustained by indomitable conviction, is more powerful than material forces that seem insurmountable".

Truth and Ahimsa for Practice by Groups and Communities of Nations

In the *Stride Towards Freedom* (1959), Martin Luther King declared "The intellectual and moral satisfaction that I failed to gain from the utilitarianism of Bentham and Mill, the revolutionary methods of Marx and Lenin the special contract theory of Hobbes, the 'back to nature' optimism of Rousseau, and the superman philosophy of Nietzsc,. I found in the non-violent resistance philosophy of Gandhi. I came to feel that this was the only morally and practically sound method open to oppressed people in their struggle for freedom".

It is important to recognise that the new Chapter—the new dimension—of collective action in the theory and practice of Ahimsa and Satyagraha opened by Mahatma Gandhi is closely interlinked with the Industrial-Scientific Revolution. It is an integral part of it. It could hardly have been possible earlier. Above all it needs rapid means for mass communications. And let us not forget that as yet we are only at the beginning of this great Chapter in man's history.

The two supreme events of our Age are, undoubtedly the discovery of nuclear energy and its use use to make nuclear weapons, and, on the other hand, the organization and use of collective Ahimsa and Satyagrah under Gandhi for the liberation of India. The Mahatma says : "We have to make truth and non-violence not matters for mere individual practice but for practice by groups and communities and nations. That at any rate is my dream. I shall live and die in trying to realize it. My faith helps me to discover new truths every day. Ahimsa is the attribute of the Soul, and therefore to be practised by everybody in all affairs of life".

I spoke of Einstein's views about Gandhi's *Ahimsa* and *Satyagraha*. At a UNESCO conference Robert Oppenheimer speaking on Einstein said that if he had to think of a single word for Einstein's attitude towards human problems, he would have to pick the Sanskrit word *Ahimsa* (*Bulletin of the Atomic Scientists*, March 1979, p. 38). [Einstein b. 14 March, 1879, d. 18 April, 1955].

And if we think of Niels Böhr, no less appropriate for him would be the word Ahimsa. The complementarity approach which we owe principally to Böhr, and which is of the profoundest significance for modern physics, is inextricably linked with the theory and practice of Ahimsa.

May I at this point refer to a remarkable reference book, "*The GAIA ATLAS of PLANET MANAGEMENT*" edited by Norman Myers, PAN (1985). It is the

book "for today's caretakers of tomorrow's world". It provides a most telling and insightful account of the interdependence, for man's survival, of science and technology and Ahimsa. The book powerfully stimulates further thought and action. A highly instructive review by Sir Eric Ashby in the *Nature* (21st March, 1985) rays : The book pricks the *conscience* of the general public".

A recent issue of the *Daedalus* (Winter 1980) is devoted entirely to the problem of technology and values. As Harvey Brooks, a lending US Professor of Technology, says : "There are those who, like myself think it (technology) is absolutely essential for survival, and there are others who think in fact it is almost the opposite......It seems to me that because technology opens up options, it takes a strong value system to control the choice of options, and so where technology is disastrous is where it enters a culture or a social situation with a weak value system and very little sense of collective welfare".

Foremost Task of Education

Technological development in general widen at a terrific pace the already frightening gap between the rich and the poor *within* a country, and between the rich and the poor countries. Never before a value system firmly and effectively committed to serve the interests of the common people was more than necessary than today. And the situation is desperate.

Science and Technology tell us what can be done and what cannot be done. Science describes the limits of the possible. But science cannot tell us what we *ought* to do. That decision, is an ethical-moral decision. Scientific truths and moral truths are not contradictory. These are complementary. It is the exploration and practice of the complementarity of *scientific* and *moral truths* that gives to life richness, dignity, beauty and happiness.

The history man's advancement in Ahimsa-taken in its widest sense—is undoubtedly the most important aspect of the history of man. Yet nearly all the history we are taught in the schools the world over including our country—the land of Gandhi is the history of himsa (violence). Karl Popper writes (*The Open Society and Its Enemies*. Vol. II p. 270); : "There is no history of mankind, there's only an 'indefinite number of histories of all kinds of aspects of human life. And one of these is the history of political power. This is elevated into the history of the world. But, this, hold, is an offence against every decent conception of mankind. It is hardly better than to treat the history of embezzlement or of robbery or of poisoning as the history of mankind. *For the history of power politics is nothing but the history of international crime and mass murder* (including, it is true, some of the attempts to supress them). This history is taught in schools, and some of the greatest criminals are extolled as its heroes".

What educational reform could be more important and crucial than to change this situation. At least, a first step in this direction is long over due. In the atomic age what could be more unfortunate and lamentable that Ahimsa the human part of human history finds no place in today's education. What could be more important and desperately needed man's survival than the theory and practice of Ahimsa finding an effective place in school education.

We may recall Eienstein's statement (20 November, 1950) so inspiring and so relevant in the Atomic Age :

"The most important human endeavour is the striving for morality in our actions. Our inner balance and even our very existence depends on it. Only morality in our actions can give beauty and dignity to life.

To make this a living force and bring it to clear consciousness is perhaps the foremost task of education.

The foundation of morality should not be made dependent on myth nor tied to any authority lest doubt about the myth or about the legitimacy of the authority should imperil the foundation of sound judgement and action".

Ahimsa and Open Society

The most gruesome mass murder in history was the dropping of atomic bombs on Hiroshima and Nagasaki in August, 1945. That decision was not taken in the *open*, but in the utmost *secrecy*. It was not a democratic decision. No one is likely to hold that deployment of weapons or mass destruction (whether atomic, chemical or biological) would be or should be done after a public debate. But few would dissent that effective decentralisation of decision-making processes tends to discourage gross misuse and perversion of power. It is also worth remembering that though there were some top scientists, in the U.S. and outside, in the know of the development of the atomic bomb, and who were against its use on Japan, none of them lodged a public protest of any kind. And, of course, no one offered or even thought of offering;*Satyagraha*. Even one utterly sincere *Satyagrahi* against the bomb, prepared to give-up everything, his life, might have influenced President Truman's conscience and the course of events. Or, it might not have. Who can tell ? But the fact is there was no *Satyagraha* against the atomic bomb.

The discovery of nuclear fission (in 1938), an epochal discovery in *pure science* was the achievement of persons with not the slightest idea or any intention whatsoever to use it for military purposes. There was no motivation other than to advance pure science—in this case the physics and chemistry of interaction of neutrons with matter. And yet within barely seven years it was applied to murder hundred of

thousands of innocent human beings. The history of man has been, as Bertrand Russell said, that if any folly or crime however cruel or despicable, was at all *possible*, then man would commit it. But, in the nuclear age man's *folly*, could put an end to all civilization, and even an end to all life. The way out is to persevere with courage and faith, individually and collectively, for an *open society* and *ahimsa* as a way of life. The great lesson of modern science and particularly biology is that the world is closely integrated, interdependent system. And, therefore, my happiness, in the long run, can only be ensured by working for the happiness of others.

Böhr [b. 7 Oct. 1885, d. 18 Nov. 1962] in his 1950 Open Letter to the UN Secretary General—a letter that expresses his deepest faith and hope said : "An open world where each nation can assert itself solely by the extent to which it can contribute to the common culture and is able to help others with experience and resources must be the goal to be put above everything else ..The very fact that knowledge is in itself the basis for civilisation points directly to openness as the way to overcome the present crisis.

The efforts of all supporters of international cooperation, individuals as well as nations, will be needed to create in all countries an opinion to voice with ever-increasing clarity and strength, the demand for an open world". Böhr's Letter forcefully reminds us of Kant's prophetic Essay (1795) on *Perpetual Peace*. It is so pertinent today.

Rajiv Gandhi—Gorbachev Declaration [Delhi 27 November, 1986]

The world is hopefully—frustratingly, agonizingly moving towards an "Open World", that is, a world based increasingly on Science *and* Ahimsa. Any other course can lead only to mankind's total annihilation. Note that *both* Science and Ahimsa are capable inherently of unlimited advancement, of ever-increasing richness and moral-spiritual upliftment.

There can be little doubt that the Gandhi-Gorbachev Declaration is a momentous step forward. In a basic sense it is a profoundly inspiring step, a landmark, in man's continuing quest along the path of *Truth and Ahimsa* which goes back to Buddha and Mahavira, and to which Mahatma Gandhi in our own times made a contribution of the utmost significance and highest value for man's future, even his very survival.

The ten principles of the Declaration are :

1. Peaceful coexistence must become the universal norm of international relations.
2. Human life must be recognized as supreme.

3. Nonviolence (Ahimsa) should be the basis of community life.
4. Understanding and trust must replace fear and suspicion.
5. The right of every state to political and economic independence must be recognized and respected.
6. Resources being spent on armaments must be channeled towards social and economic development.
7. Conditions must be generated for the individual's harmonious development.
8. Mankind's material and intellectual potential must be used to solve global problems.
9. The balance of terror must give way to comprehensive international security.
10. A nuclear weapon free and nonviolent world requires specific and immediate action for disarmament.

The editorial in *Science* [2 Oct. 1987] on *Arms and the Men* emphasizes the point that arms control "will be valuable only if we seek to understand and defuse the causes of war . ...In depth psychological studies could possibly tell us that proper education can direct national pride from jingoistic competition to constructive cooperation...We might even learn to understand ourselves, once it becomes clear that it is the only way that we are going to survive".

Ahimsa and Beyond-Science

Ahimsa is not a part of science : *Ahimsa goes beyond science. And beyond-science, beyond reason, is not anti-science or anti-reason.* Ahimsa has no meaning for *matter* (physics) as such, it has a meaning only for a *conscious being*, for an "I" of self (psyche) with free-will. To ignore this simple fact can be only ruinous.

Questions such as, *Who are we ? What is the purpose of life?*, lie beyond-reason. To understand and to endeavour to answer such "ultimate questions" is in the very nature of things an endless ever expanding quest. For such a quest, reason is *absolutely necessary*, but it is not *sufficient*. We have to go beyond reason—of course, *never* anti-reason. The basic distinction between the two concepts of *necessary* and *sufficient* is well known in mathematics, but not often appreciated in sociology and philosophy, and it has lead to untold confusion.

The case for an *open-world*—for a world based on *science* and *ahimsa* cannot be established scientifically or by *rational* arguments alone. It goes beyond science. It is a question of choice. And choice implies a value judgement. The choice here is between man's survival and universal death. And survival depends directly on the complementarity of Science and Ahimsa. The highest type of scientific activity is not possible without a supreme faith in science and in man. This is a normal quality.

There is no inherent contradiction in the same person being an intellectual giant and a spiritual pigmy, but in real life it is most unlikely. When asked (during a serious illness) whether he was at all afraid of death. Einstein said : "I feel such a sense of solidarity with all living things that it does not matter to me where the individual begins and ends". And he said, "There is nothing in the world which I could not dispense with at a moment's notice". How close to Gandhi are the ethical convictions of Einstein ! He regarded Gandhi as "the greatest man of the age".

Principle of Complementarity basically a Spiritual Concept

It is time I said something about complementarity itself. I have used the word frequently. I must admit I have not used it consistently. The concept is not an easy one, and our understanding is still rudimentary. That makes the subject interesting but also irritating.

In speaking of the complementarity of two aspects or view points, an important element is that the situations under which the two aspects occur are different in some essential respects. Complementarity of the two aspects implies some irreducible element of incompatibility between them. This is necessary.

The complementarity principle has emerged, in the modern context, from the study of atomic phenomena. The complementarity of the wave and particle aspects of matter is wellknown. The two aspects are incompatible. An experiment which demonstrates the wave aspect would automatically exclude demonstration of the particle aspect, and vice-versa. Why so ? It arises from an interaction, inherent in the nature of thing between a system and the measuring instrument. The interaction cannot be eliminated even under ideal conditions. It cannot be reduced below a certain minimum limit, defined by the Planck's constant, for any conceivable experiment—or "thought experiment". The interaction disturbs the state of the system under observation. An experiment which provides some information about an atomic system, inevitably destroys (in general) some other information which we had about the system from an earlier experiment on the system. We cannot accumulate information indefinitely, because of an unavoidable interaction between the system and the measuring device and the accompanying disturbance of the state of the system. This is totally different from the situation in the classical physics. If interaction between a system and the measuring device could be completely ignored, made zero—as was the assumption in classical physics—then, in principle, the measuring instrument becomes redundant. Not so in quantum mechanics ! The complementarity principle is forced upon us because there can be no measurement without a certain minimum interaction; and the expeiimental arrangement for determining different properties of an atomic system are, in general, incompatible with one another.

In fact, if we could think of an experiment which is inherently incapable of giving us information about some obvious, characteristic property of the system, then such an experiment is likely to reveal unexpected features of the system. This in a sense is the essence of complementarity mode of thinking in physics.

Böhr had great faith in the future role in human affairs of the practical philosophy of complementarity. It can enable people to see that seemingly irreconcilable points of view need not be contradictory. These, on deeper understanding, may be found to be complementary and mutually illuminating the two opposing, contradictory aspects being parts of a 'totality', seen from different perspectives. The complementarity approach allows the possibility of accommodating widely divergent human experiences into an underlying harmony, and bringing to light new social and ethical vistas for exploration and for alleviation of human suffering. Böhr fervently hoped that one day complementarity would be an integral part of everyone's school education, and provide guidance in the problems and challenges of life. For Böhr the complementarity approach which generated one of the greatest revolutions in natural philosophy was also of the utmost relevance for every aspect of man's life. The complementarity approach or Syadvada is indispensable for the pursuit of truth and ahimsa in all their varied aspects.

H. Yukawa, the Japanese physicist who predicted the existence of the mesons on the basis of the principle of complementarity, was asked whether young physicists in Japan found the same great difficulty in comprehending the idea of complementarity as physicists do in the West. He replied that Böhr's complementarity always appeared to them as quite evident "You see we in Japan have not been corrupted by Aristotle (Aristotle's Logic)" he added.

It is interesting to recall that Böhr as a student attended lectures on formal logic and on the history of philosophy. He liked Spinoza's concept of the psycho-physical parallelism; but later rejected it, as parallelism is not a true expression of complementarity. He read Kierkegaard. He was much impressed by Paul Muller's Tale of Danish Student, a delightful humorous story of Hegelian dialectics. A soul searching research scholar struggles desperately to unravel the intricacies of human thinking. How can thought arise in the mind ? "And before you think it, you must have had an idea of it, otherwise how could it have occurred to you to think it ? And so it goes on to infinity, and this infinity is enclosed in an instant". And while the scholar is trying to prove that thoughts cannot move, in that very process the thoughts are rapidly moving We are involved in an inexplicable contradiction, similar, in a sense, to the celebrated Zeno's paradox on the impossibility of motion of objects.

The most significant lesson we can learn from the marvellous epoch-making developments and discoveries in atomic physics in our century is not to be misled by apparent contradiction, but try to understand the *complementarity* underlying.

The great lesson we owe primarily to Niels Bőhr is that we must learn to take the complementarity approach seriously not only in science but in life. *And the philosophy of complementarity is essentially the philosophy of Upanishads* and the *Gita.*

Complementarity of Matter and Mind

The profoundest, richest and most fundamental of all *complementarities* is of course that of *matter* and *consciousness* (mind). Perhaps, Wolfgang Pauli (of the Pauli Exclusion Principle) has stated the matter most clearly and succinctly. "To us...the only acceptable point of view appears to be one that recognizes *both* sides of reality—the quantitative and the qualitative, the physical and the psychical—as compatible with each other, and can embrace them simultaneously ..It would be most satisfactory of all if *phusis* and *psyche* (i.e. matter and mind) could be seen as complementary aspects of reality. (W. Pauli in *The Interpretation of Nature and the Psyche*, (ed.) C.G. Jung and W. Pauli, Bollingen, New York, 1955, pp. 208-210).

We are gradually moving away from what is "one of the most firmly entrenched taboos of twentieth century science" that "any mingling of knowledge with values is unlawful, forbidden". The taboo is disastrous for humanism, disastrous for theory and practice of values. To man's great good fortune science—perhaps unexpectedly—is now slowly out steadfastly moving towards a more unified world view which includes both knowledge and values as complementary and mutually reinforcing.

As we have said repeatedly, scientific truths and ethical truths are not contradictory but complementary. There can be no great advancement in science without some measure of ethics in society. In the practice of science a high level of ethical norms is absolutely essential. Equally, on the other hand, in the modern world there is not much room for the practice of ethics without science and technology.

Take questions such as : Is there consciousness or mind in animals ? What about plants ? Is there consciousness in a single cell ? Do plants feel pain ? And what about bacteria and single cells ? It is apparent that these questions—essentially qualitative, *subjective*—cannot be resolved *within* the framework of *objective* science. They go beyond science. But if we accept the complementarity of matter and mind—and there seems to be no escape—then consciousness is ever present at all levels of existence – from minerals to man. Only the degree of manifestation is different. In a highly thoughful article '*Life and Mind in the Universe*'. George Wald has considered some aspects of this problem. (*International Journal of Quantum Chemistry*, 1984).

It needs to be emphasized that the wave-particle complementarity lies entirely *within* the domain of objective science. It is a direct expression of the existence of the *quantum of action* (Planck's constant). The wave-particle complementarity can

serve as a launching pad, as it were, to gain some insight into higher complementarities which lie beyond science. The deepest complementarity is of *matter* and *consciousness*—of *phusis* and *psyche*. It is ultimately, an expression of the *Vedantic Identity* : *Ataman Brahaman.* This is discussed in an illuminating manner by Erwin Schröedinger in the Epilogue to his great classic, *What is Life* ? (1944). [Also relevant to our discussion is Henri Poincare's Essay on *Ethics & Science in Mathematical Sciences*, in *Last Essays*, DOVER (1963). James Lighthill the recently *recognized failure of predictibility in Newtonian dynamics. Proc. R. Soc. Lond.* A 407 (1986)].

Notice that all living organisms are subject to the laws of physics and chemistry which make no distinction whatsoever whether the atoms are parts of a living body or otherwise. Equally, one cannot deny the incontrovertible direct experience that the motions of one's body are under his or her control. My body is a "machine" but "I" control its movements. Let us assume, as undisputed, the two facts of experience (a) My body is a machine, and (b) its motions are under my control : (a) is a scientific, and *objective fact of experience*, (b) is a *subjective fact of experience*. From these two *facts* what is the inference we can draw which would not be contradictory to science *that is* not violate the objectivity and autonomy of Natural Sciences ? The only possible inference, as Schröedinger has stressed, it that every mind that has ever said or felt "I" is the *One* (if any) who controls the 'motions of the atoms', controls the universe, according to the Laws of Nature.

Says Schröedinger : "Within a cultural milieu where certain conceptions (which once had or still have a wider meaning among other peoples) have been limited and specialised, it is daring to give to this conclusion the simple wording that it requires. In Christian terminology to say : "Hence I am God Almighty" sounds both blasphemous and lunatic. But please disregard these connotations for the moment and consider whether the above inference is not the closest a biologist can get to proving God and immortality at one stroke". And he continues "in itself, the insight is not new. The earliest records to my knowledge date back some 2500 years or more. From the early great Upanishads the recognition ATMAN-BRAHMAN (the personal self equals the omnipresent all-comprehending eternal self) was in Indian thought considered, far from being blasphemous to represent the quintessence of deepest insight into the happenings of the world. The striving of all the scholars of Vedanta was, after having learnt to pronounce with their lips, to really assimilate in their minds this grandest of all thoughts".

Notice the stunning sweep and profoundity of the argument. From two straight forward, undeniable facts of experience it leads directly to that insight or truth which irrespective of differing ideologies is, in the end, the only real foundation of all truly social and moral endeavour and activity.

Moral-Spiritual Experiments

The most significant lesson of science for ethics is that "experimentation" in ethics is as necessary for its development—its practice and philosophy—as it is in natural science. The method—par excellence—of ethical or moral "experimentation" is Ahimsa and Syadvada.

Mahatma Gandhi gave to his autobiography the title : *The Story of My Experiments with Truth*. He wrote (1926) : "what I want to achieve—what I have been striving and pining to achieve these thirty years—is self-realisation, to see God face to face, to attain Moksha (salvation). I live and move and have my being in pursuit of this goal"...The "experiments" narrated are spiritual, or rather moral, for the essence of religion is morality". And he says : "I claim for them nothing more than does a scientist...I have gone through deep self-introspection searched myself through and through, and examined and analysed every psychological situation. Yet I am far from claiming any finality or infallibility about my conclusions. One claim I do indeed make and it is this. For me they appear to be absolutely correct, and seem for the time being to be final...And so long as my acts satisfy my reason and my heart, I must firmly adhere to my original conclusions".

In the concluding chapter of *The Story of My Experiments with Truth*, Gandhiji says : "My uniform experience has convinced me that there is no other God than Truth.. and...the only means for the realisation of Truth is Ahimsa...After all, however, sincere my strivings after Ahimsa may have been they have still been imperfect and inadequate, as a result of all my experience, that a perfect vision of truth can only follow a complete realisation of Ahimsa". And he continues : "I must reduce myself to zero. So long as a man does not of his own free will put himself last among his fellow creatures, there is no salvation for him. Ahimsa is the farthest limit of humility". Speaking on Scientific truth Einstein says : "This firm belief, a belief bounds up with deep feeling in a Superior mind that reveals itself in the world of experience represents my conception of God. In common parlence this may be described as "pantheistic" (Spinoza)".

There is a chapter with the title, *Face to Face with Ahimsa*. This refers to the first Satyagraha in India initiated by Gandhiji after twenty one years of "preparation' in the South Africa. Writes Gandhiji about his meeting, early in 1917, with the indigo cultivators at Champaran (Bihar) : "It is no exaggeration, but the literal truth, to say that in this meeting with the peasants I was face to face with God. Ahimsa and Truth".

Says Gandhiji : "I began to prize non-violence only when I began to shed cowardice...The path of true non-violence requires much more courage than violence".

Gandhiji's "experiments" are moral-spiritual experiments. The basis of morality is self-control or self-conquest through self-suffering. And indeed

declared the Mahatma in Hind Swaraj : *Swaraj is self-control.* "Liberation from the bondage of the self constituted the only way towards a more satisfactory society", stated Einstein.

A discussion of science and Ahimsa immediately brings to mind recent far-reaching studies on the biology of animal and human behaviour, including aggression. Under natural conditions, animals of the same species do not kill one another. When they fight it is a kind of ritual, a play, and the fight instinctively stops short of causing fatality—Among animals of the same species the rule is harmony not killing. *But men kill one another*. It has no parallel in Nature. (An exception are rats). *It is man's invention.* Some domesticated animals, e.g. dogs, kill one another in fight between members of the same species, but this is a result of domestication. It does not occur in the wild. In the case of man, the invention of lethal weapons, and especially the use of fire arms, rendered the natural instinctive reactions to stop the fight short of fatality too slow to be effective. Man must learn and develop more quick ways of responding to a violent situation before it goes out of control as it were. This is a task for science and technology—the task, the goal, is ahimsa, not himsa. Konrad Lorenz concludes his great fascinating book *On Aggression* with the inspiring message; "I believe in the power of human reason, as I believe in the power of natural selection. I believe that this, in the not too distant future, will endow our descendants with the faculty of fulfilling the greatest and most beautiful of all commandments". (1966).

(Much valuable information on prevention of cruelty – often unspeakably cruel – to animals in scientific and medical experiments is provided by FRAME NEWS, Eastgate House, 34, Stoney Street, Nottingham NGI INE (U.K.) 'FRAME—*The Fund for the Replacement of Animals in Medical Experiments.*

The famous statement, issued in 1955, jointly by Bertrand Russell, Einstein, Yukawa and others is, if any thing, even more relevant today. The declaration of the Pugwash Movement on the occasion the 25th Pugwash Anniversary Conference in Warsaw (August 1982), signed by amongst others, nearly a hundred Nobel-Laureates, concludes :

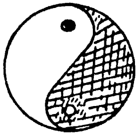
"In the circumstances in which mankind now finds itself, the warning sounded so elonquently twenty seven years ago in the Russel-Einstein Manifesto takes on a new urgency "There lies before us, if we choose, continual progress in happiness, knowledge and wisdom. Shall we, instead choose death, because we cannot forget our quarrels ? We appeal, as human beings to human beings. Remember your humanity and forget the rest".

x x x x

"Science is lame without religion and religion is blind without Science".
A Einstein.

"I shall work for an India in which the poorest shall feel that it is their country, in whose making they have an effective voice, an India in which there shall be no high class and low class of people; an India in which all communities shall be in perfect harmony..., in which the interests of the dumb millions will be scrupulously respected. This is the India of my dreams".—Mahatma Gandhi.

CONTRARIA SUNT COMPLEMENTA



Coat-of-arms Chosen by Bohr for the *Danish order of the Elephant* awarded to him (1947)

Values of the Fundamental Physical Constants

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
speed of light in vacuum	c	299792458	ms^{-1}	(exact)
permeability of vacuum	μ_0	$4\pi \times 10^{-7}$	NA^{-2}	
		$= 12.566370614...$	$10^{-7}\ NA^{-2}$	(exact)
permittivity of vacuum	ϵ_0	$1/\mu_0 c^2$		
		$= 8.854187817...$	10^{-12} F/m	(exact)
Newtonian constant of gravitation	G	6.67259(85)	$10^{-11}\ m^3kg^{-1}s^{-2}$	128
Planck constant	h	6.6260755(40)	10^{-34} J s	0.60
$h/2\pi$	$\hbar$	1.0545 7266(63)	10^{-34} J s	0.60
elementary charge	e	1.602 17733(49)	10^{-19} C	0.30
electron mass	m_e	9.109 3897(54)	10^{-31} kg	0.59
proton mass	m_p	1.672 6231(10)	10^{-27} kg	0.59
proton-electron mass ratio	m_p/m_e	1836.152701(37)		0.020
fine-structure constant, $\frac{1}{2}\mu_0 c e^2/h$	α	7.297 35308(33)	10^{-3}	0.045
inverse fine-structure constant	α^{-1}	137.035 9895(61)		0.045
Rydberg constant, $\frac{1}{2}m_e c\alpha^2/h$	R_∞	10973 731.534(13)	m^{-1}	0.0012
Avogadro constant	N_A, L	6.022 1367(36)	$10^{23}\ mol^{-1}$	0.59
Faraday constant, $N_A e$	F	96 485.309(29)	$C\ mol^{-1}$	0.30
molar gas constant	R	8.314510(70)	$J\ mol^{-1}K^{-1}$	8.4
Boltzmann constant, R/N_A	k	1.380 658(12)	$10^{-23}\ JK^{-1}$	8.5
Stefan-Boltzmann constant, $(\pi^2/60)k^4/\hbar^3c^2$	σ	5.67051(19)	$10^{-3}W\ m^{-2}\ K^{-4}$	34

Non-SI units used with SI

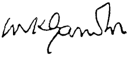
Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
electron volt, $(e/C)\ J = \{e\}\ J$	eV	1.602 17733(49)	10^{-19} J	0.30
(unified) atomic mass unit, $1\ u = m_u = \frac{1}{12}\ m(^{12}C)$	u	1.660 5402(10)	10^{-27} kg	0.59

GANDHIJI'S TALISMAN

"I will give you a talisman. Whenever you are in doubt or when the self becomes too much with you, apply the following test :

Recall the face of the poorest and the weakest man whom you may have seen and ask yourself if the step you contemplate is going to be of any use to him. Will he gain anything by it ? Will it restore him to a control over his own life and destiny ? In other words, will it lead to Swaraj for the hungry and spiritually starving millions ?

Then you will find your doubts and your self melting away".



From .— D.G Tendulkar—Mahatma Vol 8, p. 289, August 1947